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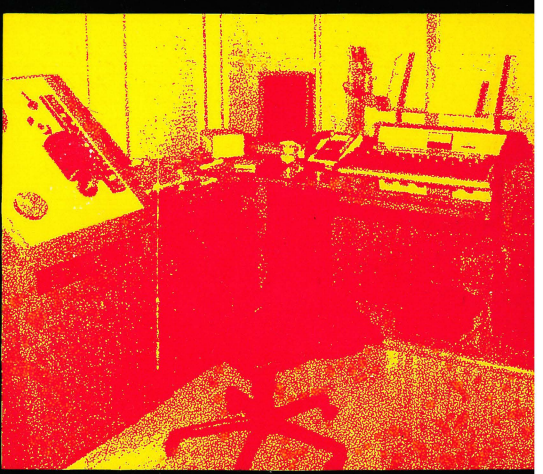
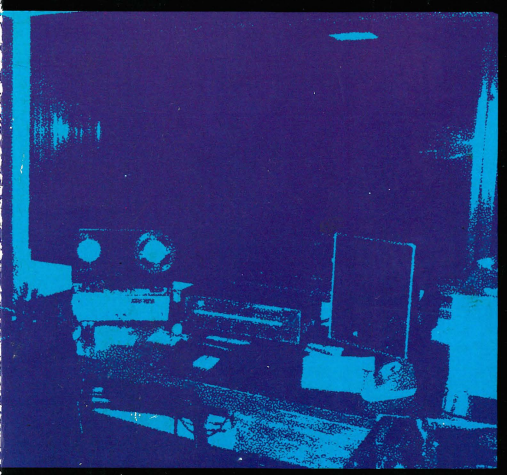
HOW TO BUILD A SMALL BUDGET RECORDING STUDIO FROM SCRATCH . . . with 12 tested designs

Everything you need to design, build, and operate your own recording studio!





by F. Alton Everest

HOW TO BUILD A SMALL BUDGET RECORDING STUDIO FROM SCRATCH . . .
with 12 tested designs

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Dedication
To
Elva

HOW TO BUILD A SMALL BUDGET RECORDING STUDIO FROM SCRATCH . . . with 12 tested designs

by F. Alton Everest

TAB TAB BOOKS Inc.
BLUE RIDGE SUMMIT, PA. 17214

FIRST EDITION

FIFTH PRINTING

Printed in the United States of America

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Library of Congress Cataloging in Publication Data

Everest, Frederick Alton, 1909-
How to build a small budget recording studio from scratch . . ., with 12 tested designs.

Includes index.
1. Sound studios—Design and construction.
2. Architectural acoustics. I. Title.
TH1725.E86 690'.5'23 79-14398
ISBN 0-8306-9787-X
ISBN 0-8306-1166-5 pbk.

Preface

This book is about small studios, how to build them and how to treat them acoustically. Details of design, construction and treatment of twelve actual studio suites are included. Acoustical principles are elucidated along the way in the context of real life projects and problems rather than blue sky theory.

The emphasis of this book is on budget studios which are eminently suited to efficient production of radio, audiovisual, film and television program material on a day-to-day, routine basis and for training students in these fields. These studios operate in a different world from the flamboyant recording studios with gold records on the wall designed to catch the eye of the well-heeled client. The operators of the studios described in this book stress function and economy over glamour and strive for good (natural, faithful) sound quality rather than achieving a new, different and distinctive sound.

The use of the word *studio* is often used in this book in the general sense to include control and monitoring rooms. Acoustical defects in the recording studio quite obviously affect the sound recorded. If the control room acoustics are poor the processing changes made by the operator may actually degrade the signal. He may be correcting for acoustical defects in his room. For this reason the same care is given to control room acoustics as to those of the studio.

The studios described in this book (with the exception of Chapter 7) follow closely, but not exactly, designs prepared by the author in his consulting practice for many different types of organizations in various parts of the world. I am greatly indebted to the following for permission to share the design of their studios with the readers of this book: Missionary TECH Team, Longview, Texas (Chapter 3); proposal submitted to the Christian Church in Zaire (Chapter 4); Hong Kong Baptist College, Kowloon, Hong Kong (Chapter 5); The Russ Reid Company, Pasadena, California (Chapter 6); Centro Bautista De Communicaciones, Montevideo, Uruguay (Chapter 8); Golden West Broadcasting Ltd., Altona, Manitoba, Canada (Chapter 9); The Paraguay Mission, Southern Baptist Convention, Asuncion, Paraguay (Chapter 10); Medios Educativos, A.C., Mexico City, Mexico (Chapter 11); Baptist Caribbean Media Center, Nassau, Bahamas (Chapter 12); Cathedral Films, Westwood Village, California (Chapter 13); and Far East Broadcasting Company, LaMirada, California (Chapter 14).

F. Alton Everest

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Chapter 1

My Studio—How Big and What Shape?

Feature: Understanding the room resonance problem.

The radio broadcasting industry nourished the "talk booth" concept in the early years. The size of the speech studio need be only large enough to accommodate one person, or possibly another for an interview, a table, a few chairs, and a microphone. In this way the telephone booth sized studios were sanctified with very serious built-in acoustical problems. To understand the source of these problems we must realize that a roomful of air is a very complex acoustical vibrating system. In fact, it is a series of many resonant systems superimposed upon each other forming a super complex problem.

Let us consider a rectangular studio 12 feet high, 16 feet wide and 20 feet long (ratios 3:4:5) such as sketched in Fig. 1-1. First we shall pay attention to the two opposite and parallel N-S walls, neglecting for the moment the effects of all the other surfaces. Even though acoustically treated to some extent, some sound is reflected from these surfaces. For sound to travel a distance of one round trip between the two walls, or 2L feet, it takes a certain, finite length of time. This time is determined by the velocity of sound which is about 1130 feet per second (about 770 miles per hour). At a frequency of 1130/2L Hz this pair of opposing, parallel walls L feet apart comes into a resonance condition and a standing

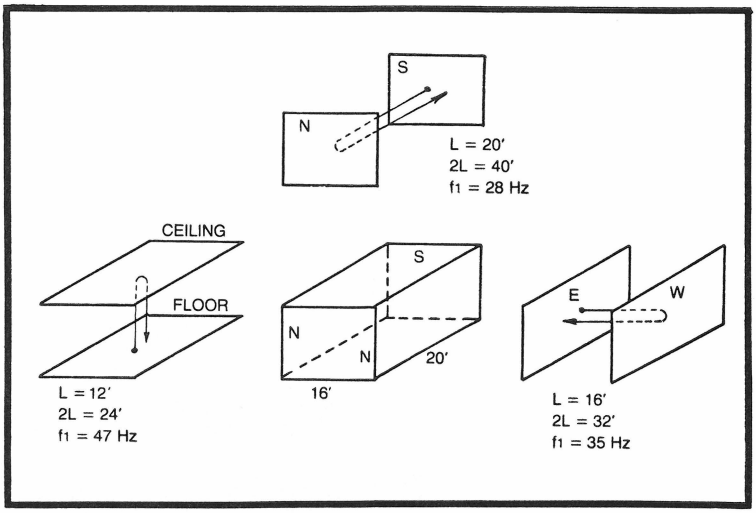


Fig. 1-1. The six surfaces of a rectangular room are broken down into 3 pairs of opposite and parallel surfaces when considering axial mode room resonances. Each pair has its fundamental resonance frequency and train of harmonics.

wave is set up. For example, in the N-S pair of walls in Fig. 1-1, L=20 feet and the frequency of resonance is 1130/40 or approximately 28 Hz.

This resonance effect also appears at every multiple of 2L. In other words there are harmonics of 28 Hz appearing at 56, 84, 112, 140.....etc., Hz. The single pair of walls then gives us a fundamental frequency and a train of harmonics at which resonance effects also occur. These are called axial mode room resonances. The E-W walls (Fig. 1-1) give another fundamental frequency of 35 Hz and a train of harmonics. The floor-ceiling combination gives a fundamental frequency of about 47 Hz and a third series of harmonics. These modal frequencies determine the *sound* of a room. They yield bad effects only if they pile up at certain frequencies or are spaced too far apart, as we shall see later.

We have considered only axial modes of this room involving a single pair of surfaces. There are also tangential modes involving two pairs of surfaces and oblique modes involving three pairs of surfaces which have still different fundamental frequencies and harmonics (Fig. 1-2). Taken all together, these make the sound field of an enclosed space extremely complex. Fortunately for us, the effect of tangential and ob-

can get by quite easily and reasonably accurately in designing a studio by considering only the axial modes, although we depend on the resonance effects of tangential and oblique modes to do a certain amount of filling in between the axial modes.

Any sound energy near 28 Hz in the space between the N-S walls gets a resonance boost. Because of the standing wave effect the sound pressure at 28 Hz is far from uniform across the room, being very high near the surface of the N and S walls and zero at the center of the room. The situation is very much like the organ pipe closed at both ends. At the second harmonic near 56 Hz, however, the distribution of sound pressure in the standing wave is quite different, having two null points and a maximum in the center of the room as well as at each wall surface. When complex sounds of speech or music excite the fundamental and harmonics of a single series there is extreme complexity between a single pair of wall surfaces as the standing wave patterns shift. Adding the effects of the E-W and vertical modal series and adding the tangential and oblique modes results in a constantly shifting sound field, the complexity of which defies description[1].

HOW BIG SHOULD A STUDIO BE?

Each room resonance frequency has a certain bandwidth (or Q)[6]. The ideal situation would be to have adjacent resonances (fundamentals and harmonics) locked arm in arm with neighbors through these resonance skirts. This results in signal components of constantly fluctuating frequency being

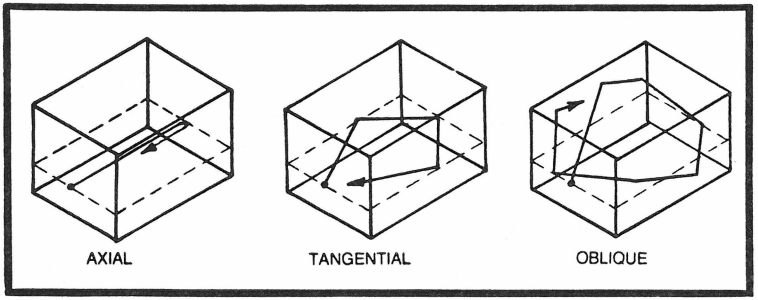


Fig. 1-2. Axial modes involve two surfaces; tangential modes four surfaces; and oblique modes six surfaces. The axial modes commonly dominate small studio acoustics.

[1]All references are found at the conclusion of this book.

Table 1-1. Axial Resonance Frquencies

	N-S Walls (2L = 40 ft.)	E-W Walls (2L = 32 ft.)	Floor-Ceiling (2L = 24 ft.)
f_1 (fundamental)	28.3 Hz	35.3 Hz	47.1 Hz
f_2 (2nd harmonic)	56.5	70.6	94.2
f_3 (3rd harmonic, etc.)	84.8	105.9	(141.3)
f_4	113.0	(141.3)	188.3
f_5	(141.3)	176.6	235.4
f_6	169.5	211.9	(282.5)
f_7	197.8	247.2	329.6
f_8	226.0	(282.5)	
f_9	254.3	317.8	
f_{10}	(282.5)		
f_{11}	310.8		

treated uniformly. If the spacing of these resonances is too great, some of our precious signal energy is boosted by resonances and some falling "in the cracks" discriminated against. On the other hand, if three or four room resonances occur at the same frequency or are very close together, signal energy in this part of the spectrum would receive an abnormal boost. Such pile-ups are inevitably accompanied by gaps elsewhere in the spectrum. Good studio sound requires careful attention to these resonance frequencies which are, in turn, controlled by room dimensions and proportions.

Room size determines how the low frequencies are treated. The larger the room, the lower the frequency components the room can support. Small rooms result in great spacing of room modes. A talk booth of 6 feet × 8 feet could not support sound lower than about 70 Hz. Even though there is little energy in voice below 150 Hz, such a small room is unsuitable for recording because of excessive mode spacing. The BBC has found that any studio of less than 1500 cubic feet is not practical. Any saving in construction cost is outweighed by cost of correcting acoustical deficiencies—and usually successful correction of deficiencies is not feasible.

DISTRIBUTION OF MODES

We have considered the three axial frequencies and the three series of harmonics of the studio of Fig. 1-1. Now we must ask the question, "Are these frequencies properly dislique modes is less than that of the axial modes. Basically, we

page 12

tributed?" To answer this, each frequency must be computed and examined. This may be a bit tedious, but it involves only the simplest mathematics. A convenient approach is to tabulate the series for each of the three room dimensions, such as in Table 1-1. We notice several things: that 141.3 Hz and 282.5 Hz occur in each column and that they bear a 2:1 relationship to each other. These coincident frequencies are called *degeneracies* by the scientist. How well the other modal frequencies are distributed overall is difficult to see from columns of figures. In Fig. 1-3 each modal frequency is plotted on a linear frequency scale. Each mode is represented by a vertical line, although actually each one has an average bandwidth of about 5 Hz (as sketched for the lowest mode of Fig. 1-3). The triple coincident frequencies at 141.3 and 282.5 Hz are seen to be greatly spaced from their neighbors. The piling up at 141.3 and 282.5 Hz means that signal energy near these frequencies will be unnaturally boosted. Also, the great separation from neighboring modal frequencies guarantees that signal components in these gaps will be unnaturally depressed. This adds up to almost certain audible colorations at these two frequencies that are monotonous and repetitive blasts of energy which distort music and are particularly obnoxious in speech.

DECIDING ON BEST STUDIO PROPORTIONS

The 3:4:5 proportion of Figs. 1-1 and 1-3 is ill-suited for studio construction because of poor modal distribution. What room proportions should be used? Numerous studies have

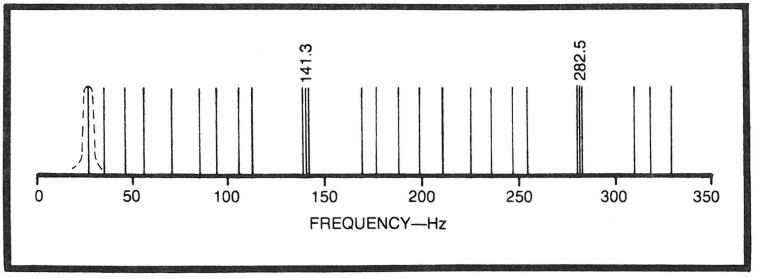


Fig. 1-3. The axial mode frequencies of a rectangular room 12 × 16 × 20 feet are shown as lines, although each has a bandwidth of approximately 5 Hz. as indicated on the extreme left. Three coincident frequencies at 141.3 and 282.5 Hz. are separated slightly for clarity.

Table 1-2. Studio Proportions

	Ratios	Ceiling Height, ft.	Length ft.	Width ft.	Volume cubic ft.
(A)[7]	1:1.14:1.39	10.0	13.9	11.4	1585
(B)[7]	1:1.28:1.54	10.0	15.4	12.8	1971
(C)[7]	1:1.60:2.33	10.0	23.3	16.0	3728
(D)[8]	1:1.90:1.40	10.0	19.0	14.0	2660
(E)[8]	1:1.90:1.30	10.0	19.0	13.0	2470
(F)[8]	1:1.50:2.10	10.0	21.0	15.0	3150

been made on this subject and reported in the literature. Three suggestions from each of two authors are presented in Table 1-2. In this table, studio dimensions following the suggested ratios are included based on a ceiling height of 10 feet. The studio volume, which varies from example to example, is included for each ratio.

For a visual comparison of these ratios, the fundamental and harmonic series is plotted for each in Fig. 1-4. Although there are scattered double coincidences, all six show better distribution than the unfortunate 3:4:5 choice of Fig. 1-1. Yet none shows the equally spaced modal frequencies desired in our ideal studio. Nor should this bother us too much. It is just as bad to place too much emphasis on room proportions as it is to neglect them completely.

The presence of people and furnishings in a room so affects the actual modal frequencies that it is futile to worry over minor deviations from some assumed optimum condition. A practical approach is to be alert to problems of coincidence and mode spacing; to do what can be done to optimize them and then relax. If an existing space is being considered as a studio or control room, check the modal frequencies after the fashion of Table 1-1 and plot them as in Fig. 1-4 to see if serious problems exist. For new construction, do the same for proposed dimensions of any sound sensitive rooms. A liberal education in axial modes awaits the persevering student who varies one dimension of a room (on paper) while holding the others constant and noting how the modal distribution is affected. One soon concludes that eliminating coincidences is a major victory and beyond that there is little to be gained.

In Table 1-2 the ceiling heights of the room are held constant and volume allowed to vary. If the several proportions were adjusted so that the volume remained constant, the ratios would draw closer together. This is illustrated in Table 1-3 in which the ratios of Table 1-2 are adjusted so that all volumes are the same as that corresponding to the first ratio. In other words, when rooms of the same volume but of different proportions are considered, the six ratio examples we have been studying are not as different from each other as they first appeared to be. However, they are different, relatively speaking, and we cannot escape the fact that smaller dimensions yield higher fundamental frequencies.

The fundamental resonance frequencies and harmonics of the ratios of Table 1-3 adjusted for the same room volume are plotted in Fig. 1-5. Figures 1-4A and 1-5A are, of course, identical as they represent the common point of comparison in the two cases. Although frequencies are shifted, a family

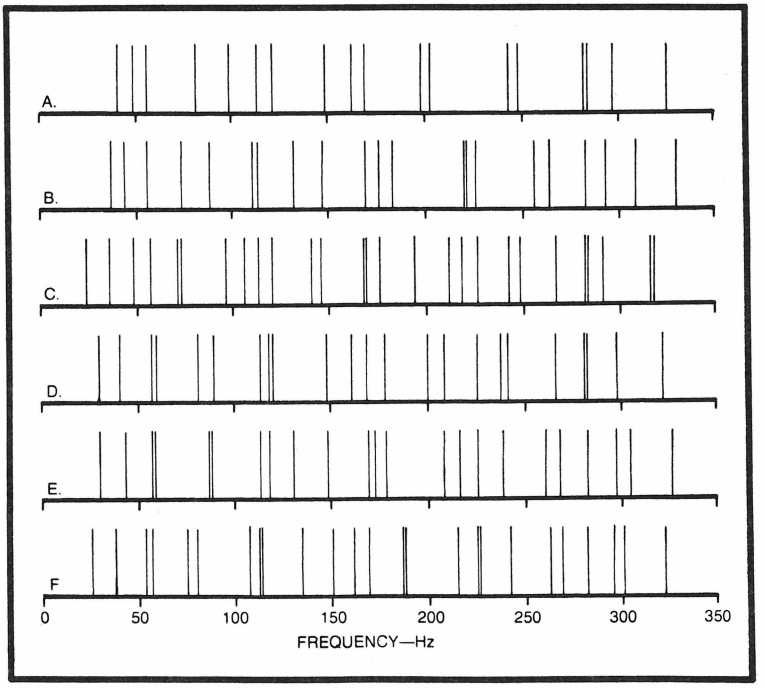


Fig. 1-4. A plot of axial mode frequencies of six of the best studio dimension ratios listed in Table 1-2. Lines representing coincident frequencies are slightly displaced in several instances for clarity.

Table 1-3. Varying Proportions With The Same Volume

	Ratios	Ceiling Height, ft.	Length ft.	Width ft.	Volume cubic ft.
(A)	1:1.14:1.39	10.0	13.9	11.4	1585
(B)	0.93:1.19:1.43	9.3	14.3	11.9	1585
(C)	0.75:1.20:1.75	7.5	17.5	12.0	1585
(D)	0.84:1.60:1.18	8.4	16.0	11.8	1585
(E)	0.86:1.64:1.12	8.6	16.4	11.2	1585
(F)	0.80:1 19:1.67	8.0	16.7	11.9	1585

resemblance can be seen when comparing Figs. 1-4B and 1-5B, Figs. 1-4C and 1-5C and other corresponding pairs. The coincident or nearly coincident pairs of Fig. 1-4 still exist in Fig. 1-5. In general, however, the larger rooms of Fig. 1-4 have the advantage of yielding closer average spacings.

STUDIO SIZE AND LOW FREQUENCY RESPONSE

An inspection of the left edge of the six plots of Fig. 1-4 reveals that the larger rooms have lower fundamental frequencies than the smaller ones. In Fig. 1-6 the fundamental room resonances corresponding to the longest dimension of the six cases are plotted against room volume. For the smallest studio (Fig. 1-4A) having a volume of 1585 cubic feet, the lowest signal frequency which would have the advantage of resonance assistance is about 41 Hz. The studio of Fig. 1-4C, however, with its volume of 3728 cubic feet can handle signal components down to 24 Hz. For speech purposes, the smaller studio is quite adequate because speech energy below 40 Hz is extremely low. The 3728 cubic foot studio adds almost another octave in the lows which would be quite advantageous for music recording.

This discussion has been based on the axial modes of a room. The tangential and oblique modes have somewhat longer paths and hence would tend to extend the low frequency limit of a room. While axial modes have two reflections per round trip, tangential modes have four and oblique modes have six (refer again to Fig. 1-2). As energy is lost at each reflection, the reason for the lower amplitudes of tangential and oblique modal resonances is apparent.

However, axial reflections are perpendicular to the surfaces, the angles of incidence which give the most efficient

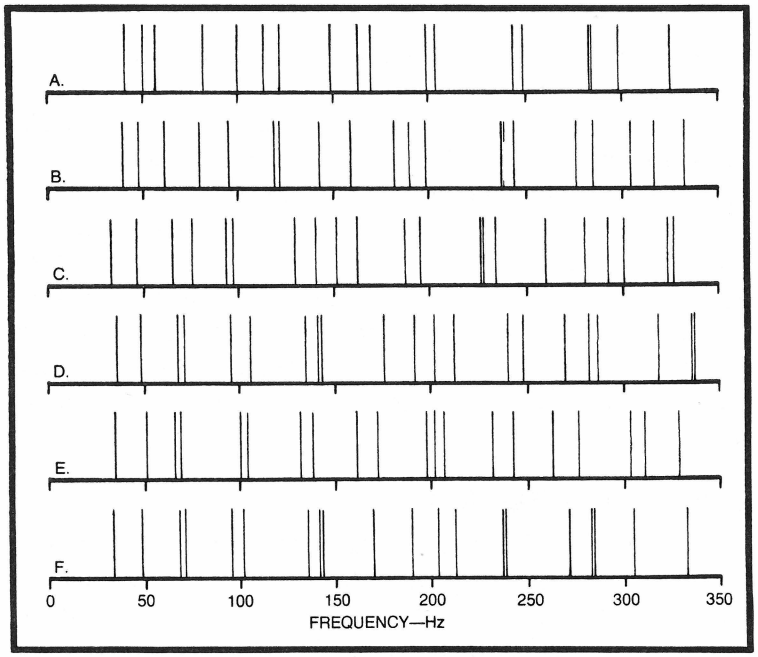


Fig. 1-5. A plot of axial mode frequencies of the same six examples of dimensional ratios of Fig. 1-4 but adjusted for the same room volume of 1585 cubic feet. Some coincident lines are displaced slightly for clarity (Refer to Table 1-3).

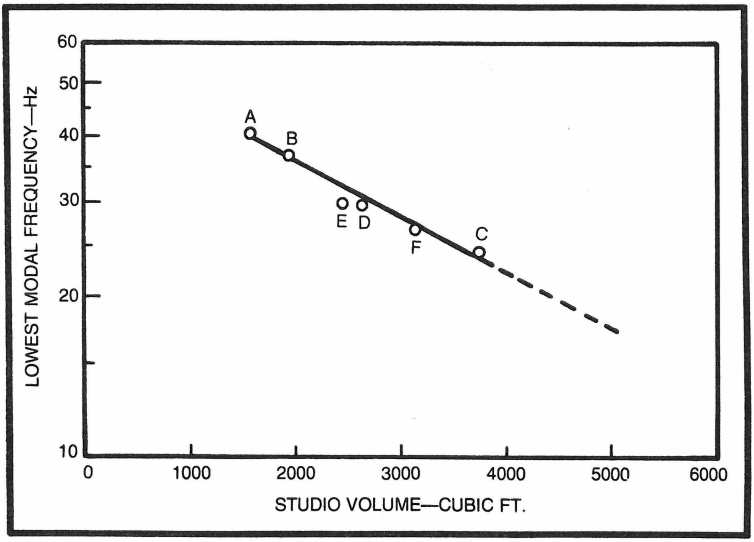


Fig. 1-6. The six lowest modal frequencies of Fig. 1-4 as related to room volume. A 4000 cubic foot studio adds one octave to the room's low frequency response as compared to a studio of 1500 cubic foot volume.

absorption. Tangential and oblique modal paths, while involving more reflections, are usually at smaller angles of incidence. This results in less absorption at each reflection. The limit is grazing incidence at which absorption is very small. Thus, the number of reflections for tangential and oblique is greater than for axial modes, but, acting in the other direction, there is the fact that the smaller angles of incidence result in less loss per reflection than the 90° incidence of axial modes. How do these opposing factors add up? As has been stated, the axial modes are more dominant than the tangential and oblique modes. Therefore, the practical extension of a room's low frequency response due to tangential and oblique modes is limited.

ROOM CUTOFF FREQUENCY

Every studio has some frequency above which the modal frequencies are close enough together to merge into a statistical continuum. This is called the cutoff frequency of the room. At frequencies higher than the cutoff frequency, various components of the signal will be treated more or less uniformly and the room will act more like a large auditorium. At frequencies below cutoff, excessive spacing of modes exists with resulting uneven treatment of signal components.

The cutoff frequency of a room is a function only of its reverberation time and volume and may be computed approximately from the following statement[9]:

$$\text{Room cutoff frequency} = 20{,}000\sqrt{\frac{T}{V}}$$

where,
T = reverberation time, seconds
V = volume of room, cubic feet

Figure 1-7 is computed from this basic statement for volumes and reverberation times common in small studios. The larger and the more dead a studio, the lower the cutoff frequency and the less difficulty in handling the low end of the audible spectrum. In Figs. 1-3, 1-4 and 1-5 the plots of modal frequencies were terminated at about 300 Hz which approxi-

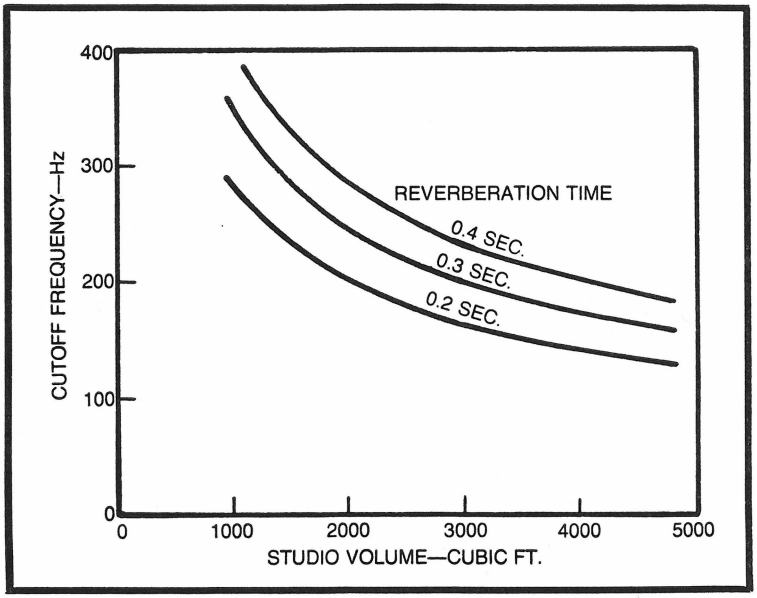


Fig. 1-7. The cutoff frequency of a room is that frequency above which modes are numerous enough and close enough together to merge into a statistical continuum. Cutoff frequency is determined only by the volume and reverberation time of the room.

mates the cutoff frequency of the average small studio above which modes are increasingly closer together.

SUMMARY OF ROOM MODE EFFECTS

- Rooms smaller than 1500 cubic feet are subject to insurmountable room mode problems and should be avoided for quality recording studios and control rooms. The larger the room, the closer the average spacing of modal frequencies and the more uniform the treatment of the various components of the signal.
- In choosing studio proportions, try to eliminate coincident frequencies below 300 Hz. Multiple coincidences in the region below 200 Hz are more apt to cause audible colorations than those between 200 and 300 Hz.
- Once multiple coincident frequencies are reduced or eliminated it is futile to carry modal analyses to

extremes because occupants, furnishings and other room irregularities result in great deviations from the idealized paper condition.

- The splaying of studio walls may be helpful in reducing flutter echo, but modal frequencies are only shifted to some unknown values. Splaying may also tend to break up degeneracies (coincident frequencies) in an otherwise symmetrical room, but keeping things under control by choosing proper proportions of a rectangular room is a satisfactory approach if flutter echo and diffusion are controlled by proper placement of absorbing material.
- What can be done to treat an unavoidable coloration in a studio? A tuned Helmholtz resonator can be introduced to tame the coincident frequency. The sharpness of tuning may have to be controlled to avoid the slow decay of sound in a high-Q structure. The construction and tuning of such absorbers will be discussed in later sections.

Chapter 2

Elements Common to All Studios

Features: Sound lock treatment, doors and their sealing, combating air conditioner noise, wall constructions, floor-ceiling constructions, wiring precautions, lighting, observation windows, the permit.

Each of the 12 studio plans to be studied in this book has certain elements in common with all the others. For example, all require protection from interfering noise, whether it originates outside or inside the studio. All studios require an observation window for visual contact between the control operator and those in the studio. Since it would be ridiculous to repeat descriptions of each of these common elements a dozen times, this chapter is designed to make such a course of action unnecessary.

SOUND LOCK ACOUSTICAL TREATMENT

The acoustical treatment requirements of a typical sound lock corridor will keep coming up unless they are considered once for all. The sound lock places two doors in series and two walls in series so that external noise must traverse both to penetrate to the quiet rooms. Many examples of sound locks sharing common principles and differing only in details will be seen in the studio plans to be considered.

Functionally, the sound lock both isolates and absorbs. Wall construction, which is one way of achieving isolation, is considered later in this chapter as well as the treatment of doors and door seals.

In this section the lining of the sound lock is the topic. As a person enters a sound lock from the outside, the exterior noise momentarily floods the corridor. A sound level reading outside the open door would be higher than one inside the sound lock, even with the door open, if the interior surfaces are highly absorbent. The sound transmitted through a sound lock corridor is significantly reduced if the corridor surfaces are properly treated.

Consider an untreated corridor (average absorption coefficient, say, 0.1) and the same corridor with surfaces treated (average absorption coefficient 0.9). By adding the absorbing material the noise level in the sound lock would be reduced as much as 9.5 dB from the bare condition. Even if both the exterior door and the studio door were open at the same time (an unusual occurrence), the exterior noise level in the studio would be reduced by about this amount due to the inner treatment of the sound lock alone. This is why it is so important to make sound lock surfaces as absorbent as possible.

Although sound locks come in all shapes and sizes, the treatment alternatives of Fig. 2-1 are representative. Heavy carpet and pad is the almost universal solution for the sound lock floor. Of the numerous approaches for the ceiling, the ubiquitous suspended ceiling supported by a T-grid offers many advantages. The better grade of lay-in panels offer absorption coefficients averaging 0.75 to 0.85 throughout the 125 Hz—4 kHz band. They give excellent low frequency absorption which is further increased by introducing a thick layer of household insulation into the cavity above the lay-in panels. Manufacturers specify coefficients for the standard Mounting 7 in which the lay-in ceiling is 16 inches below the structural ceiling. Other distances may be used, of course, with some modest change in absorption. A lay-in ceiling of this type provides an ideal hidden location for air conditioning ducts and electrical service runs.

Another approach is covering ceilings and upper walls with common acoustical tile or 2 to 4 inches of dense glass fiber

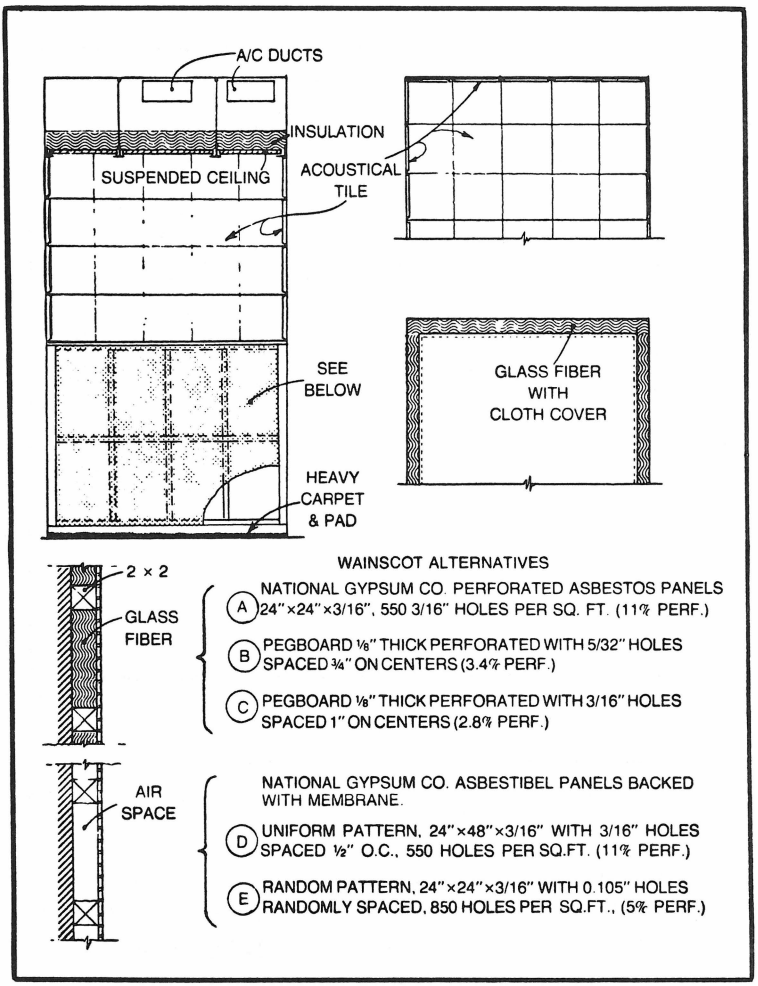


Fig. 2-1. Alternate approaches to the acoustical treatment of the sound lock corridor. To minimize noise being transmitted through the sound lock it should be very absorbent, although the requirements otherwise are not critical.

boards. The latter require some sort of protective cover such as expanded metal, wire screen, or loosely woven cloth. Cloth has the advantage of controlling the sluffing off of tiny, irritating glass fibers.

The lower walls must withstand considerable mechanical abrasion. There are dozens of proprietary panels which would serve well in this location, but all are expensive. One straightforward and inexpensive approach is to mount panels

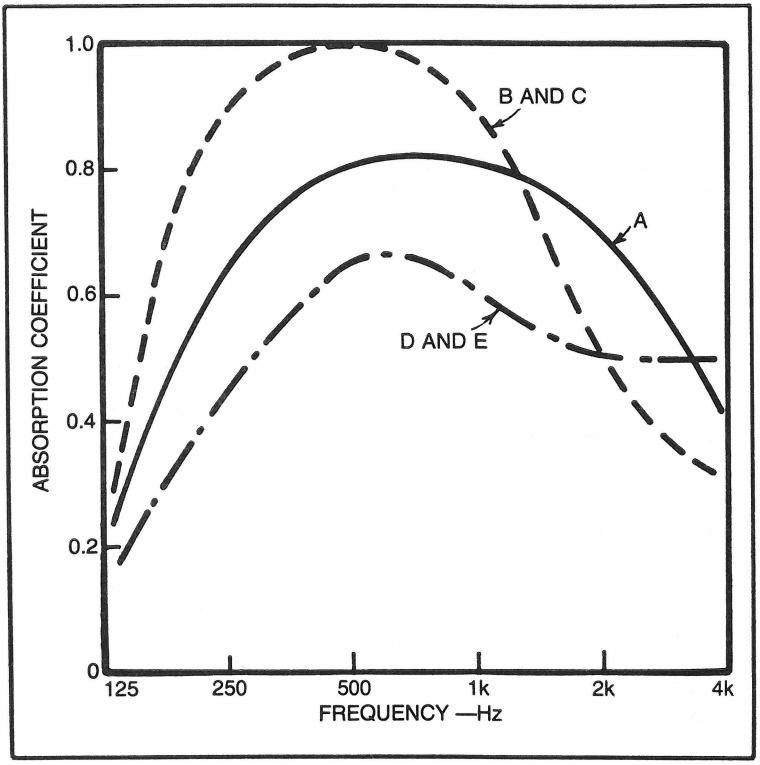


Fig. 2-2. Approximate absorption characteristics of the alternate wainscot treatments of Fig. 2-1.

of Tectum (Gold Bond Building Products Division of National Gypsum Co.), a structural board of wood fiber with a cement binder. It stands up well under abuse and may be painted with minimum effect on acoustical properties. A 1 inch layer of Tectum over an air space obtained by furring out on 2 × 2s gives excellent absorption coefficients of 0.75 to 0.85.

Figure 2-1 shows five other approaches utilizing 2 × 2 furring and commercially available perforated facing boards. The absorption coefficients of these arrangements and their variations with frequency are shown approximately in Fig. 2-2. Within the very loose acoustical criteria applicable to sound locks, these may be considered comparable and interchangeable. In general, high absorption in the more audible mid-frequency range is preferable to uniformity of absorption throughout the band.

ACOUSTICAL DOORS

The access to each studio-control room suite should be via a sound lock. This means that all doors open off the sound lock. The use of a sound lock relaxes door requirements in that heavy loaded and laminated doors with awkward ice box type of clamping hardware are eliminated. However, at the opposite extreme, ordinary household doors are far too thin acoustically to be acceptable. A reasonably inexpensive intermediate solution is the 1¾ inch solid core doors which are readily available. Such doors have solid wood or particle board cores which provide the density necessary to impede the flow of sound through them. A typical particle board core faced with ⅛ inch hardboard has a density of 5.3 pounds per square foot of surface. This gives a transmission loss of 33 dB at 500 Hz on

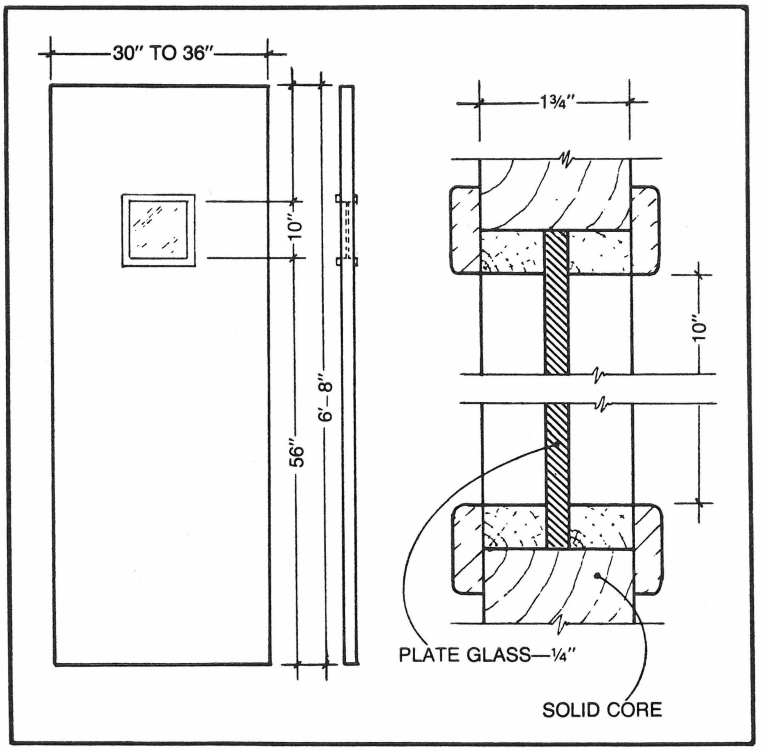


Fig. 2-3. Plans for an acceptable solid-core door for studio, control room and sound lock use. The sound lock places two such doors between high level noise sources and sound sensitive areas. The window prevents collisions and allows appraisal of the situation in a room before entering.

a mass law basis. In common with other barriers, its transmission loss is less than this amount below 500 Hz and greater above 500 Hz. This would be insufficient alone, but the sound lock principle places two such doors in series between a high noise area (exterior or control room monitor loudspeaker) and the studio.

A 10 inch × 10 inch window in each door (Fig. 2-3) reduces the possibility of injury by a door opened suddenly. It also allows visual appraisal of the situation in a room before entering. Such a window of ¼ inch plate glass, adequately sealed, will not seriously deteriorate the acoustical quality of the door but will add materially to functional efficiency.

Some people think that upholstering a door makes it "more acoustical." As far as transmission loss through the door is concerned, such vinyl cloth covering over a sheet of foam rubber and studded with large-headed tacks is a waste of time and effort. However, such a covering would offer sufficient high frequency absorption to reduce unwanted reflections or flutter echoes.

WEATHERSTRIPPING OF DOORS

A hermetically sealed door is the ideal type from an acoustical standpoint. Such a condition can be approached in sound lock doors by careful installation of common weatherstripping materials. These are available in a host of different configurations. Figure 2-4 illustrates only representative types. Strips of foam or felt in the form of metal backed strips, rolled beading or gummed strips are shown in Fig. 2-4A. Strip magnets, enclosed in flexible plastic as shown in Fig. 2-4 B, are attracted to mild steel strips imbedded in the door, effectively sealing the opening. These are of the type commonly used in refrigerator doors and they can provide an excellent acoustical seal.

The sides and top of a door are easier to seal than the bottom. A wiping rubber seal is held in place by a shaped metal or plastic retainer in Fig. 2-4C. In Fig. 2-4D a mechanical threshold closer automatically lifts as the door is opened and drops on closure. The types of weatherstripping in Fig. 2-4A are usually considered impractical for door bottoms because in such a position they take a beating from passing shoes. For

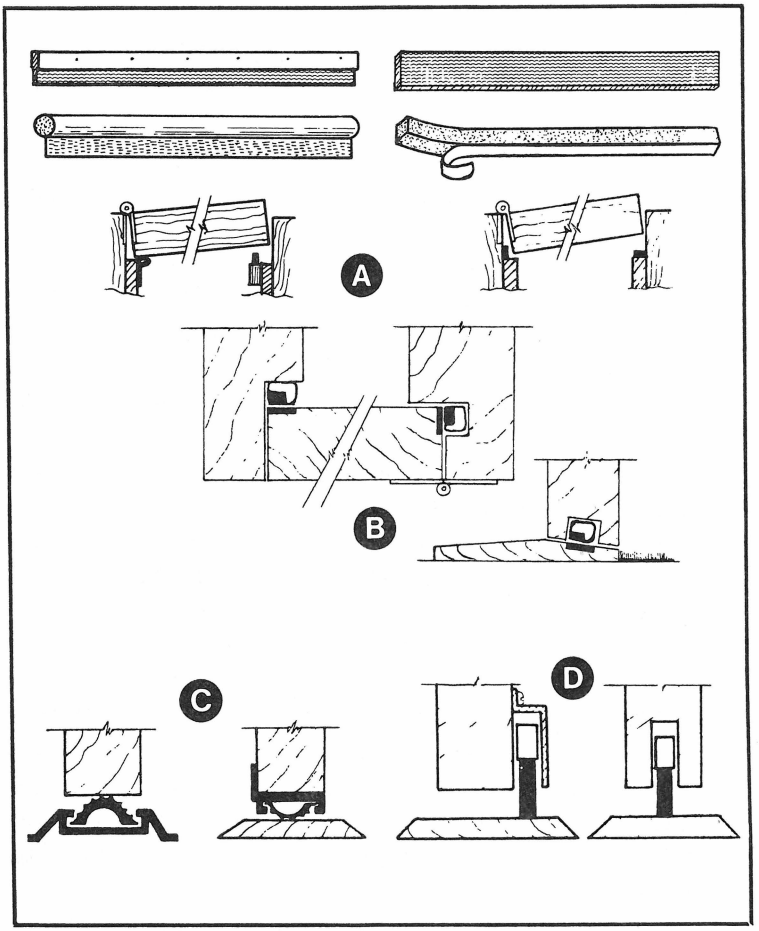


Fig. 2-4. Some of the ways to weatherstrip doors to reduce sound leaks: (A) foam or felt strips, (B) magnetic seals such as used on refrigerator doors, (C) wiping rubber seal and (D) automatic drop seal.

this reason, one of the types shown in B, C or D are far more effective at the threshold.

All of the door sealing methods pictured in Fig. 2-4 require periodic inspection to assure a continuing tight seal. Occasional adjustments are required by some and complete replacement by others as foam and felt deteriorate. Less obvious, door seal maintenance should be added to the studio maintenance reminder list which normally stops at such things as amplifier response, recorder head alignment and cleaning, etc.

HVAC NOISE

It is a difficult word to pronounce, but HVAC stands for heating, ventilating and air conditioning facilities. In this book the term *air conditioning* (A/C) includes heating and ventilating. With proper advance precautions, A/C equipment noise in the sound sensitive studio and control room areas need not be a problem. In practice, it is very often a problem because the higher standards required in recording studios are infrequently encountered by architects, building contractors and air conditioning equipment suppliers and installers.

What background noise level is acceptable in recording studios? Single figure noise levels, lumping the entire audible frequency range together, are of very limited value. For this reason noise criteria curves have been proposed for adoption as standards. Figure 2-5 illustrates a family of such curves. The N-20 contour, it will be noted, conveniently passes through 20 dB level at 1 kHz, the N-30 contour at 30 dB, etc. The corresponding NC-20, NC-30 and other NC curves which may be encountered are contours of similar shape proposed earlier but displaced upward about 3 dB for the low sound levels of interest here. There is also a proposed PNC (preferred noise criteria) standard. None have been adopted as yet.

The downward slope of these curves reflects both the ear's increasing sensitivity with increasing frequency and the spectral shape of common noises decreasing with increasing frequency.

An N-15 contour is a reasonably stringent, though usually quite attainable, noise specification and goal for recording studios. An N-20 contour is a more relaxed specification for less critical recording. The sound analysis contours of Fig. 2-5 are for octave bands of noise. Sometimes single frequency hums or whines associated with motors or fans stand out prominently from the general background of distributed noise. The peaks of such single frequency components determine the N rating contour applicable. Thus, if the noise levels in all bands were below the N-15 contour except one which reached the N-30 contour, the N-30 would apply to that noise rating. The contours of Fig. 2-5 offer a means of specifying the maximum permissible noise from air conditioning facilities or from other sources.

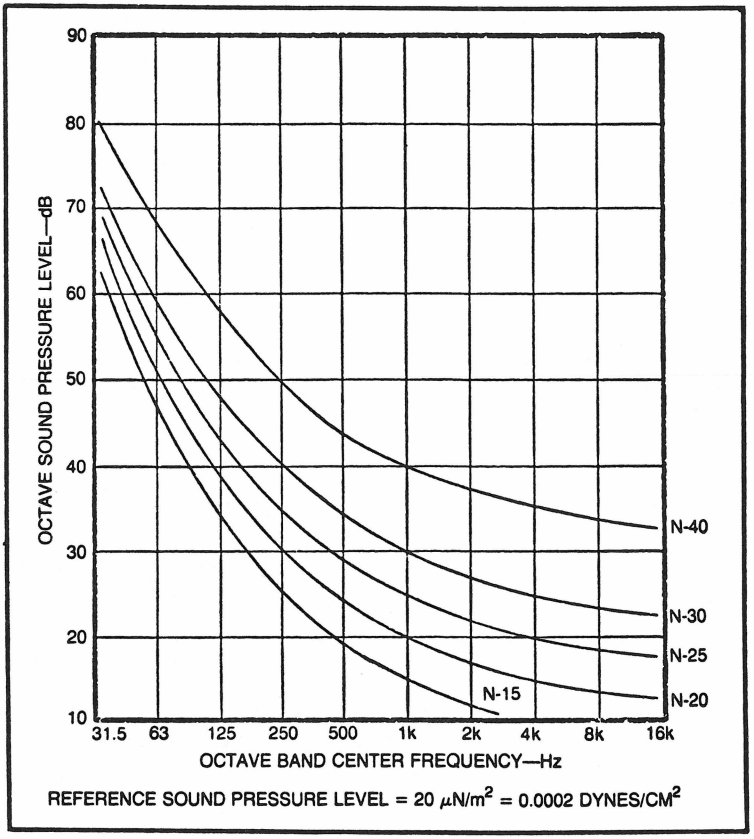


Fig. 2-5. Noise criteria curves useful in assessing noise or specifying maximum allowable noise levels in studios and other sound sensitive areas.

The ducting arrangement of Fig. 2-6A illustrates a method of reducing crosstalk between adjacent rooms through the duct from grille to grille. By avoiding serving adjacent rooms directly from the same duct (supply or exhaust), the duct path is lengthened and attenuation via the duct path increased. The greater the length of lined duct and the more lined bends between one grille and the next, the greater the attenuation and the less the crosstalk.

Figure 2-6B isolates the effect of absorptive duct lining on the attenuation of sound through the duct. Note that high frequency noise is absorbed better than low frequency noise. The 2 inch thick liner attenuates sound down the duct better than 1 inch thickness.

Figure 2-6C pictures the effect of a lined duct bend. The attenuation is greater at high frequencies than low, unfortunately similar to the straight lined duct. If we lay down an arbitrary rule that a minimum of 15 feet of lined duct and two lined bends be installed between any two adjacent rooms, what kind of attenuation of crosstalk from room to room can we expect? The curves help us to roughly estimate the following:

	Attenuation		
	250 Hz	1 kHz	4 kHz
15′ lined duct (1″ lining)	15 dB	33 dB	27 dB
2 lined bends	4	10	20
Total	19 dB	43 dB	47 dB

This dramatically illustrates the fact that duct attenuation is easier to achieve at high frequencies than in the low frequency region. Placing 30 feet of ducting between rooms would increase the total 250 Hz attenuation to 34 dB. The hums and whines often occur in the 125 or 250 Hz bands. Another possibility not detailed here is to use a sharply tuned duct stub (acoustical band reject filter) to attenuate a troublesome single frequency noise component.

It is usually easier to combat noises at their source than to introduce adequate attenuation downstream. The lined plenum of Fig. 2-6D, which offers excellent attenuation across the band, may be inserted in the duct between the A/C machinery and the sound sensitive areas. Baffles in the plenum increase the high frequency attenuation, although as noted above, adequate high frequency attenuation is usually available elsewhere. In some installations a large step-inside plenum or air chest is part of the basic equipment. If this plenum is lined with acoustically absorbent material, the noise travelling down the ducts is greatly reduced and the larger the plenum, the greater the low frequency attenuation.

Air velocity is commonly higher in the budget A/C installations than in the more professional jobs. The air velocity should never exceed 500 feet per minute at the grilles to avoid generating excessive hissing noise due to air turbulence.

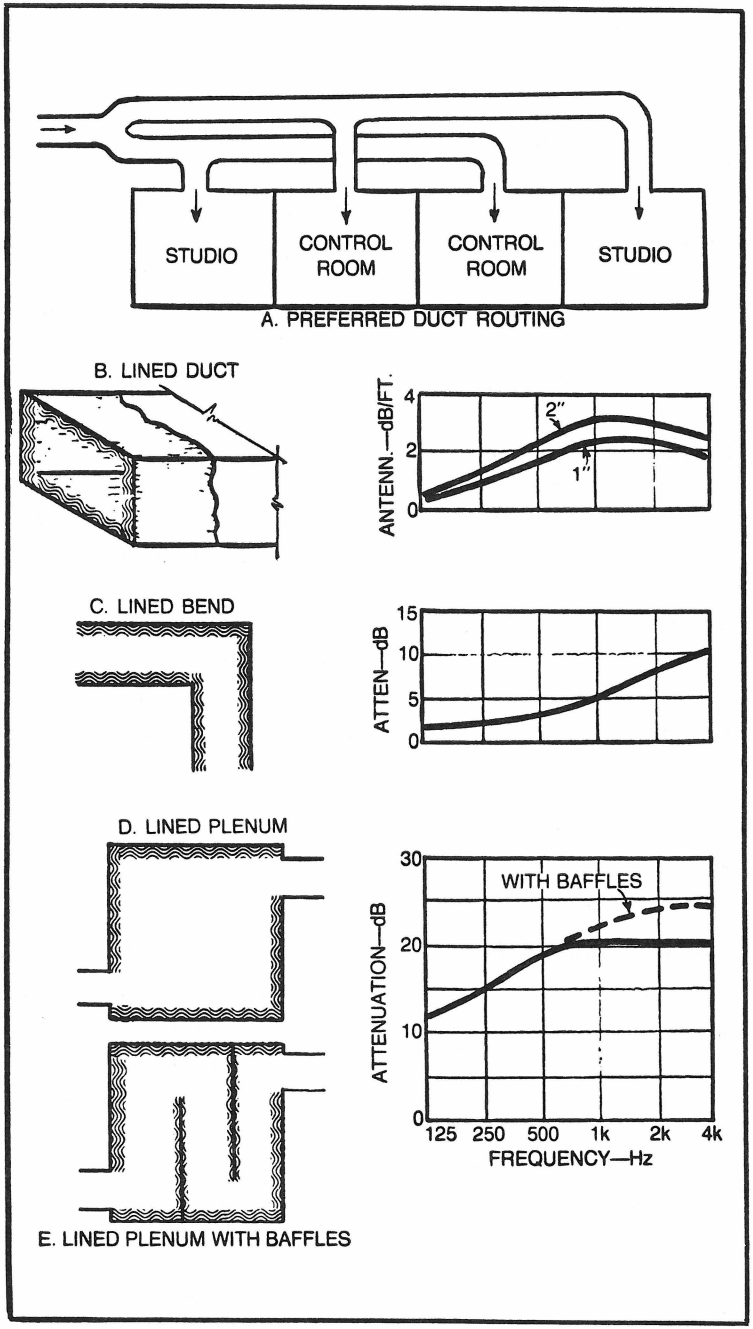


Fig. 2-6. Means of reduction of air conditioner noise in studios and the reduction of crosstalk between adjacent rooms via a duct path.

WALL CONSTRUCTION

The common 2 × 4 frame wall construction with a single layer of gypsum drywall on both sides is shown in Fig. 2-7A. It is included as a point of comparison only; its sound transmission class rating of STC 34-38 is too low for walls contingent with studios and control rooms. However, it could be used for sound lock walls not touching studios and control rooms. This wall can teach us several things. (Sound transmission loss of a wall varies with frequency. To achieve a convenient rating scheme a standard contour has been adopted which, when applied to the actual characteristic of a wall, results in a single number rating called the *Sound Transmission Class*, STC. Think of the STC rating number as a sort of average midband transmission loss in dB.)

For example, insulation in the cavity of this type of wall, with both faces closely coupled by being nailed to the same 2 × 4s, increases transmission loss only modestly. Another problem is that both faces vibrate as diaphragms. As they are identical they resonate at the same frequency and at this frequency there is a sort of *acoustical hole* in the wall. By making the faces of different thicknesses, of different densities or supporting them in different ways, the two resonances are made to occur at different frequencies, improving the wall performance. The caulking of the perimeter, of at least one face but preferably both, seals the tiny cracks that are inevitable in normal construction.

RESILIENT MOUNTING

There is a very substantial improvement in transmission loss if gypsum board on one face is screwed to a resilient channel as in Fig. 2-7B. This must be done carefully, with screws designed for the purpose, or else the resilient channel might be "shorted out."

For example, if a screw that is too long hits a stud, the resilience is lost. Acoustical elements, cabinets or shelves attached to such walls must be mounted carefully lest the extra expense and effort of using the resilient channel are destroyed by solid contact of the gypsum board with the studs.

If a double layer of gypsum board is required on a resiliently mounted wall, the base layer is attached vertically with

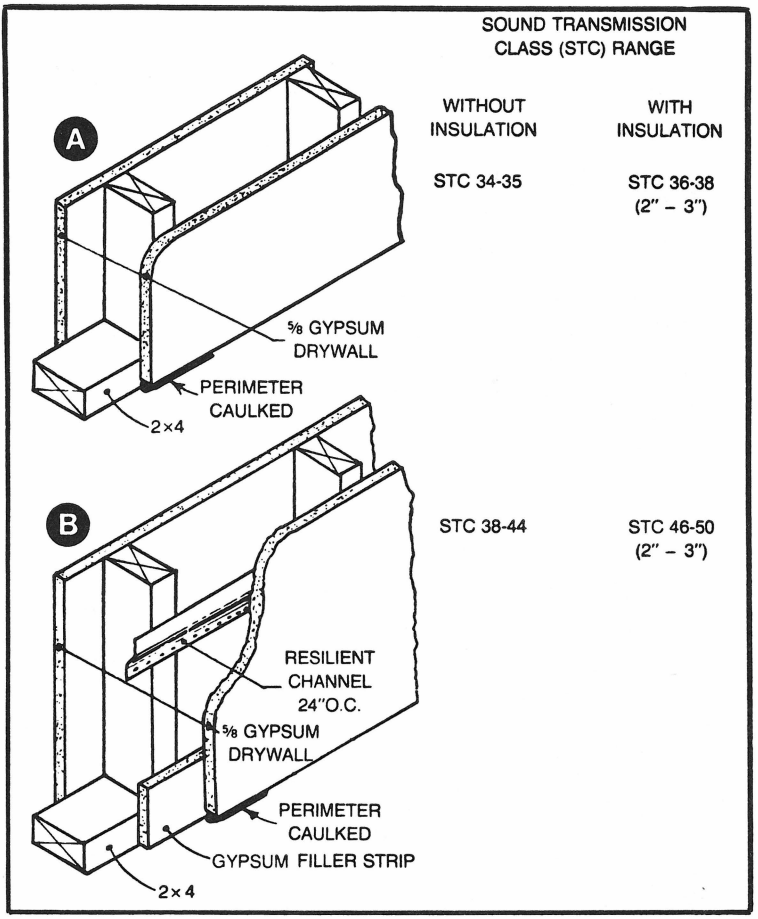


Fig. 2-7. A comparison of wall constructions in regard to their ability to shield sound sensitive areas against intruding noise: (A) common single stud wall for comparison and (B) single stud wall with resilient mounting of one face.

screws and the face layer cemented in place following the manufacturer's recommendations.

STAGGERED STUD CONSTRUCTION

Figure 2-8A shows typical staggered 2 × 4 studs with 2 × 6 plate. This eliminates the solid connection of one wall diaphragm with the other except around the periphery. This does essentially the same thing as mounting one of the wall diaphragms resiliently as in Fig. 2-7B and the STC results are somewhat comparable.

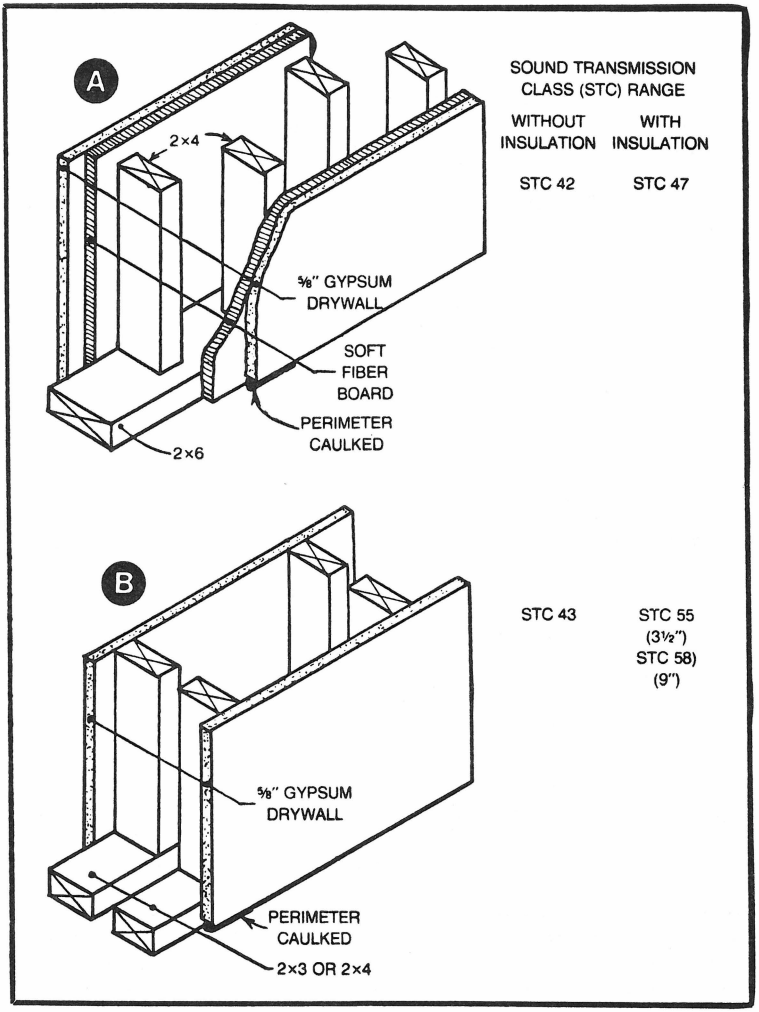


Fig. 2-8. A comparison of wall constructions of (A) a staggered stud wall and (B) a double stud wall.

An additional feature of Fig. 2-8A is the use of soft fiber boards under each gypsum layer as sound deadeners. Because of their low density such soft boards contribute little to transmission loss directly, but they do serve as frictional elements in dampening vibrations of the gypsum diaphragms.

Nailing is the common method of supporting both the soft base layer and the gypsum face layer. In Fig. 2-8A both sides are identical which, as we have seen, is less desirable than

making one side differ from the other. One satisfactory combination is a layer of ⅝ inch gypsum board over a ½ inch layer of soft sound deadening board on one side and a double layer of ⅝ inch gypsum on the other side. With ample insulation fill a staggered stud wall with such facings adequately caulked comes close to STC-50 which is a good value for normal studio walls. Further, it has been shown that the effectiveness of the filler insulation depends on thickness, but is independent of density. Therefore, the cheaper household thermal type of insulation is quite adequate for the filling of acoustical walls.

DOUBLE WALLS

Double wall frame construction is shown in Fig. 2-8B. There is only a minor difference between walls framed of double 2 × 3s and 2 × 4s. The two wall diaphragms are still connected at the periphery through a common foundation (concrete floor?) which is somewhat less coupling than that provided by a common plate in staggered stud construction. The double 2 × 3 wall, if carefully constructed and sealed, can reach STC-55 to 58 with proper insulation fill.

CONCRETE AND MASONRY WALLS

In new construction and in some cases of renovation, concrete or masonry walls are a viable choice. Ratings that apply to several common walls are found in Table 2-1. Practi-

Table 2-1. Transmission Loss in Concrete And Masonry Walls

Wall	Sound Transmission Class
Concrete—4 inches	STC-48
Concrete—8 inches	STC-52
Concrete blocks—4 inches	STC-40
Painted both sides	STC-44
Plastered both sides	STC-44
Concrete block—8 inches	STC-45
Painted both sides	STC-46-48
Plastered one side	STC-52
Concrete block—8 inches Voids filled with well-rodded concrete and plastered both sides	STC-56

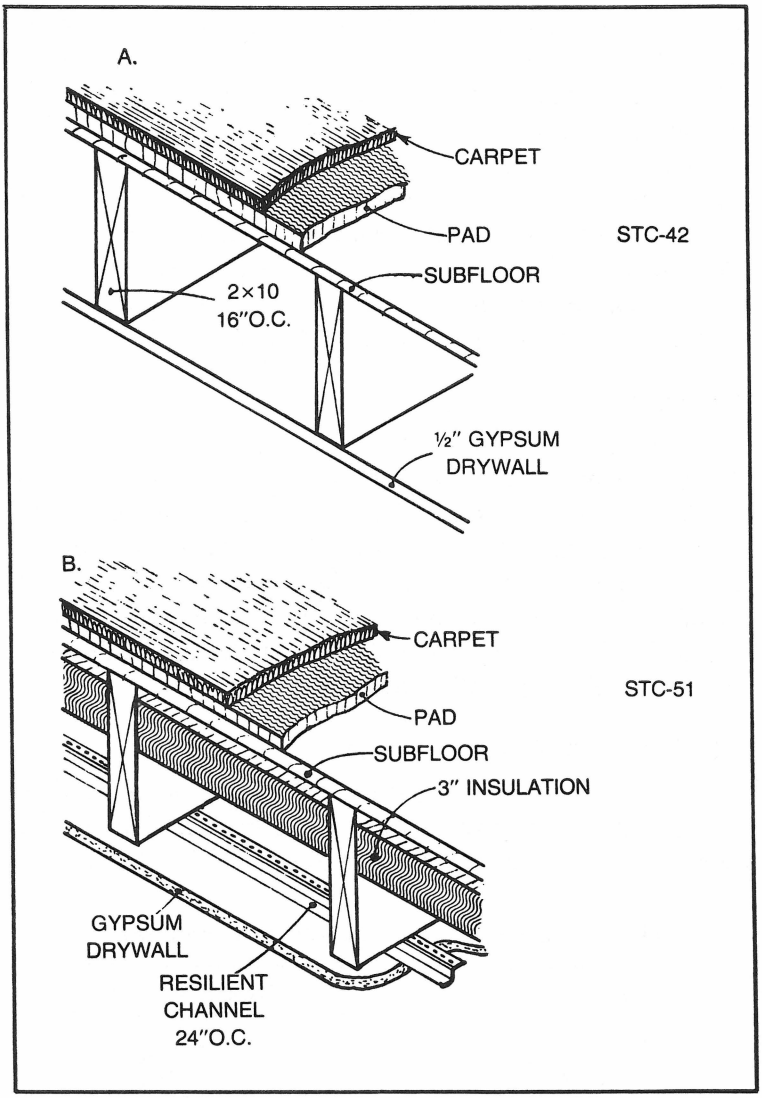


Fig. 2-9. Two methods of protecting a studio from noise from the floor above with frame construction: (A) with normal gypsum board ceiling and (B) with resiliently mounted ceiling and insulation in the air space.

cal concrete and masonry walls are seen to be quite comparable to framed walls in their STC ratings. The hard walls are somewhat inferior in another way—that of efficiently conducting structure borne impulse noises from afar and reradiating them into sound sensitive areas.

FLOOR-CEILING CONSTRUCTION

If the space above a studio is occupied and people are stalking around with hard-heeled shoes, the situation calls for careful attention. Impulsive sounds of this type penetrate to an extent that noises of other types seem tame by comparison. Floor-ceiling construction becomes very important in such cases. The construction in Fig. 2-9A is very common and the carpet helps to reduce footfall noise. The STC-42 rating, however, is marginal for most budget studios. The construction in Fig. 2-9B yields STC-51 by adding a resilient ceiling below and some insulation in the cavity between the floor joists.

ELECTRICAL WIRING

Building a 50 dB wall and then loosely mounting electrical boxes back to back is an exercise in futility. A surprising

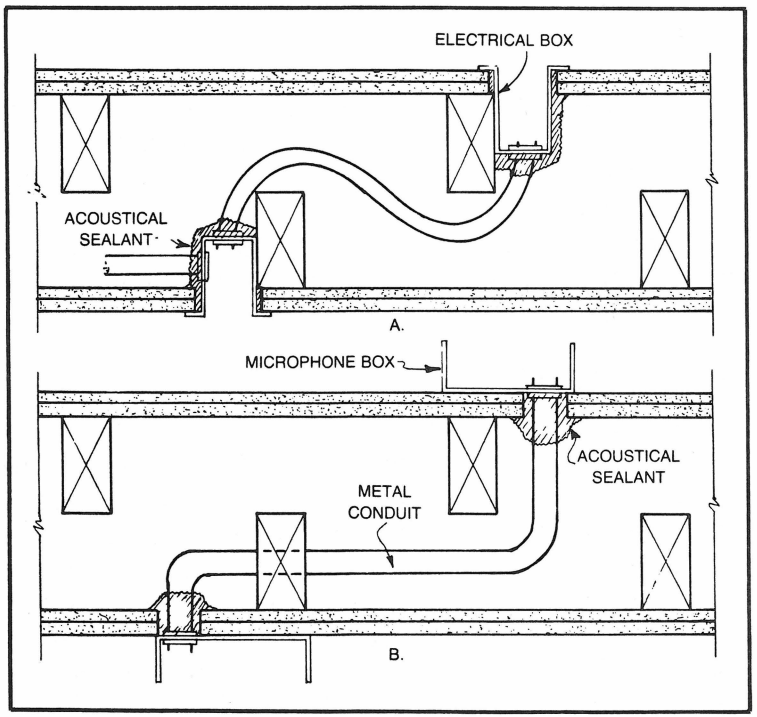


Fig. 2-10. Treatment of wiring boxes with acoustical sealant to reduce sound leaks: (A) recessed electrical boxes and (B) surface mounted microphone boxes.

amount of sound can leak through a very tiny opening and through small areas of thin spots in a wall. Electrical boxes are necessary, however, and Fig. 2-10A suggests staggering them and using copious quantities of acoustical sealant to seal openings and beef up the boxes. Surface boxes for microphone connectors reduce compromising the wall and they may be handled as shown in Fig. 2-10B. In addition to sealant at the ends of the metal conduit, it is well to also pack glass fiber tightly around the audio pairs to avoid sound travelling through the conduit itself.

LIGHTING

If fluorescent lighting is considered, the ballast reactors should be removed from the fixtures and mounted in a metal box in the sound lock or completely outside the suite. Although this takes more wire, it removes the buzzes these reactors are famous for generating outside the recording and sound evaluating areas.

Track lighting fixtures have the advantage of flexibility in concentrating the light where it is needed and hiding the light source from the eyes of those in the other room. This is the proper way to eliminate troublesome reflections in the observation window glass.

Light dimmers of the selenium controlled rectifier type create electrical noises which might give trouble in the low level microphone circuits.

OBSERVATION WINDOW

An observation window plan for staggered stud and double wall construction is shown in Fig. 2-11A. The window frame is in two parts, one nailed to the studs on the control room side and the other to the studs on the studio side. In this way the glass on each side is an extension of its own wall and has no solid connection to the other side. It is well to position felt or sponge strips in this gap between the two frames to prevent accidental solid contact between them. A comparable wall for single leaf construction is shown in Fig. 2-11B. Beads of non-hardening acoustical sealant seal off tiny cracks between the window frame and the walls in both types.

Each glass plate is a resonant system as is the air cavity between. By utilizing glass plates of different thicknesses the effects of plate resonance are minimized by preventing them from occurring at the same frequency. The cavity resonance is controlled by utilizing an absorbent reveal periphery. This may be acoustical fiber-board or glass fiber of the 703 type (Owens-Corning Fiberglas Corporation Type 703 industrial glass fiber semi-rigid boards of 3 pounds per cubic foot density. This material will be used widely in the studio designs to be described) with a cloth cover, or even strips of heavy carpet.

In any event, this periphery between the glass plates should be black or of a dark color to avoid attracting undue attention to it. Each glass plate is isolated from its retaining stops and the frame by strips of neoprene or sponge rubber. The strips bearing the weight of the glass plates should not compress more than about 20 percent under load, but the side

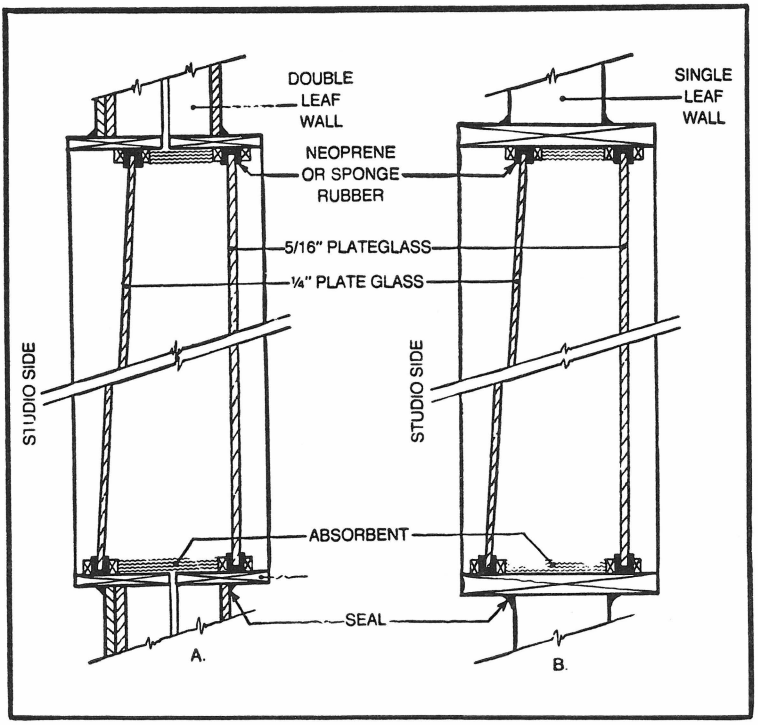


Fig. 2-11. Plans for observation window having high transmission loss: (A) for a double leaf wall (staggered stud, double stud, or double masonry walls), and (B) for single leaf wall.

strips may be much more pliant. It is well to fasten the stops on one side at least with screws so that the inside surfaces of the glass plates may be reached for cleaning if necessary.

CONSTRUCTION PERMIT

It is imperative that a construction permit be obtained before work is started. This requires plans and specifications. During construction, inspections can be expected covering structural, electrical and plumbing installations. Obtaining the permit gives evidence that zoning restrictions are met and gives assurance that fire and other insurance will not be invalidated at a later time.

Chapter 3
Audiovisual Budget Recording Studio

Features: "Contracarpet" ceiling, standing a room "on end" to get volume, detailed calculation of reverberation time.

Here is the problem presented by the client: to build a small, repeat small, studio and control room suitable for producing sound tracks for audiovisual presentations such as filmstrips, slide sets and 16 mm motion picture film shorts. It was to be placed inside a large prefabricated building with ample headroom, but floor space at a premium. On top of this, the cost must be held to an absolute minimum. Quality performance; bottom dollar. This message is familiar enough and occurs often enough to suggest a detailed treatment of the solution.

STUDIO

Speech is the predominant sound to be recorded, to which is added canned music and sound effects from subscription disc or tape libraries in the editing process. This means that the 1500 cubic foot minimum room volume discussed earlier would be acceptable for the studio. The floor plan of Fig. 3-1 provides a studio with a floor area of 158.5 square feet and, with a 10 foot ceiling, a volume of 1585 cubic feet. The dimensional ratio of 1:1.14:1.39 distributes axial modes quite well as shown in Fig. 1-4A and Table 1-2A. The two closest

modes near 283 Hz are high enough in frequency to be unlikely to cause voice colorations. A studio of these dimensions will have a response down to 40 Hz which is more than adequate for voice.

CONTROL ROOM

The high ceiling of the prefabricated building allows a control room ceiling of any reasonable height to be specified. This suggested the possibility of standing the control room on end, so to speak, to minimize floor space. The dimensional ratio of Fig. 1-4B and Table 1-2B of 1:1.28:1.54 was selected over the dimensions in Table 1-2A because a longer (or, in this case, higher) room results.

The elevation sketch in Fig. 3-1 shows the ceiling of the control room at 13 feet-9 inches. The 9.0 feet × 12.8 feet × 13.75 feet dimensions of this control room are slightly different from the case of Table 1.2B (10.0 feet × 12.8 feet × 15.4 feet), but are close enough for us to use Fig. 1-4B to get a qualitative view of mode spacings.

The two modes near 124 Hz, only 2.3 Hz apart, alert us to possible voice colorations at that frequency. The three just below 250 Hz are probably high enough in frequency to be less troublesome. We must remember, however, that voice recording is done in the studio and here we are considering only things which might affect listening conditions in the control room.

SOUND LOCK

The sketch in Fig. 3-1 includes a tiny sound lock corridor to control the effects of entering from the noisy exterior as well as traffic between the studio and control room. This places two doors in series for any given path which eliminates the need for expensive, special acoustical doors with their awkward clamping hardware and seals. Also, it allows studio access and egress during recording without a blast of noise from monitor loudspeaker or outside. Sound locks should always be a part of any studio suite intended for professional or quasi-professional use.

Stealing space for the sound lock from the control room affects the modal situation in the control room. The pristine

rectangular room with the usual three axial modes now has two other modes added, those associated with the M and N dimensions of Fig. 3-1. These dimensions of about 8.0 and 5.5 feet reduce average mode spacing, which is good, but increase the possibility of coincidences, which is bad. Because these small dimensions resonate at higher frequencies we can expect their effect to be less noticeable. A detailed examination in such cases will always alert us to a potential coloration problem.

WORK TABLE

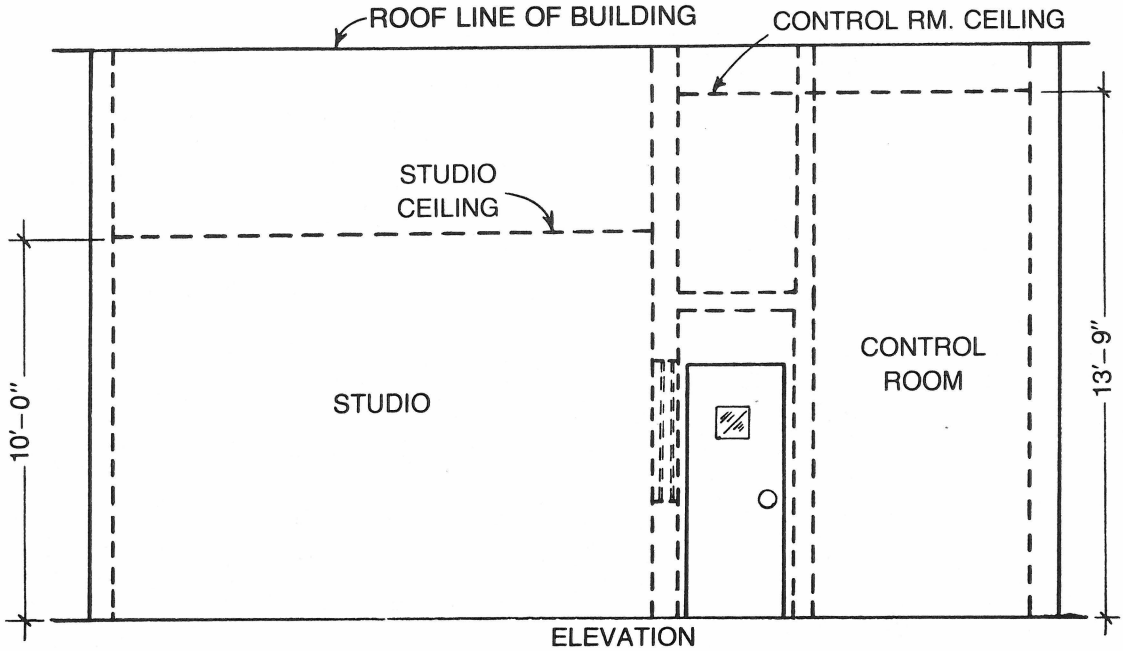
A control room dedicated to audiovisual activity needs work table space. For this reason a built-in work bench with some drawer and cabinet space below is suggested. The mixing console for such an activity would normally be one of the simple desktop models and the recorders expected would be of the advanced audiophile type which require table space rather than floor space.

STUDIO CONTRACARPET

When the client says, "Carpet on the studio floor," the acoustical consultant gulps and bravely says, "Can do!" Carpet plays a dominant role in the acoustics of the studio because the floor area is a substantial part of the total surface area of the room; the problem is that carpet absorbs well at higher frequencies and very poorly at lower frequencies. Carpet on the floor dictates compensating absorbers peaking at low frequencies and this often means tuned Helmholtz units.

In the elevation of Fig. 3-1 the studio and control room walls run all the way to the roof. This is necessary to prevent flanking sound travelling from one room to the other via the "attic." Establishing an acoustical ceiling in the studio can be easily done by suspending it with common metal angles and Tees and wires. However, instead of the usual 24 inch × 48 inch soft fiber lay-in panels, the special *countercarpet* panels detailed in Fig. 3-2 are used.

BBC engineers have used the term *anticarpet* to denote an absorber to compensate for the carpet deficiencies. However the term *contracarpet* seems to be somewhat more de-


ROOF LINE OF BUILDING
CONTROL RM. CEILING
STUDIO
CEILING
STUDIO
CONTROL
ROOM
10'–0"
13'–9"

ELEVATION

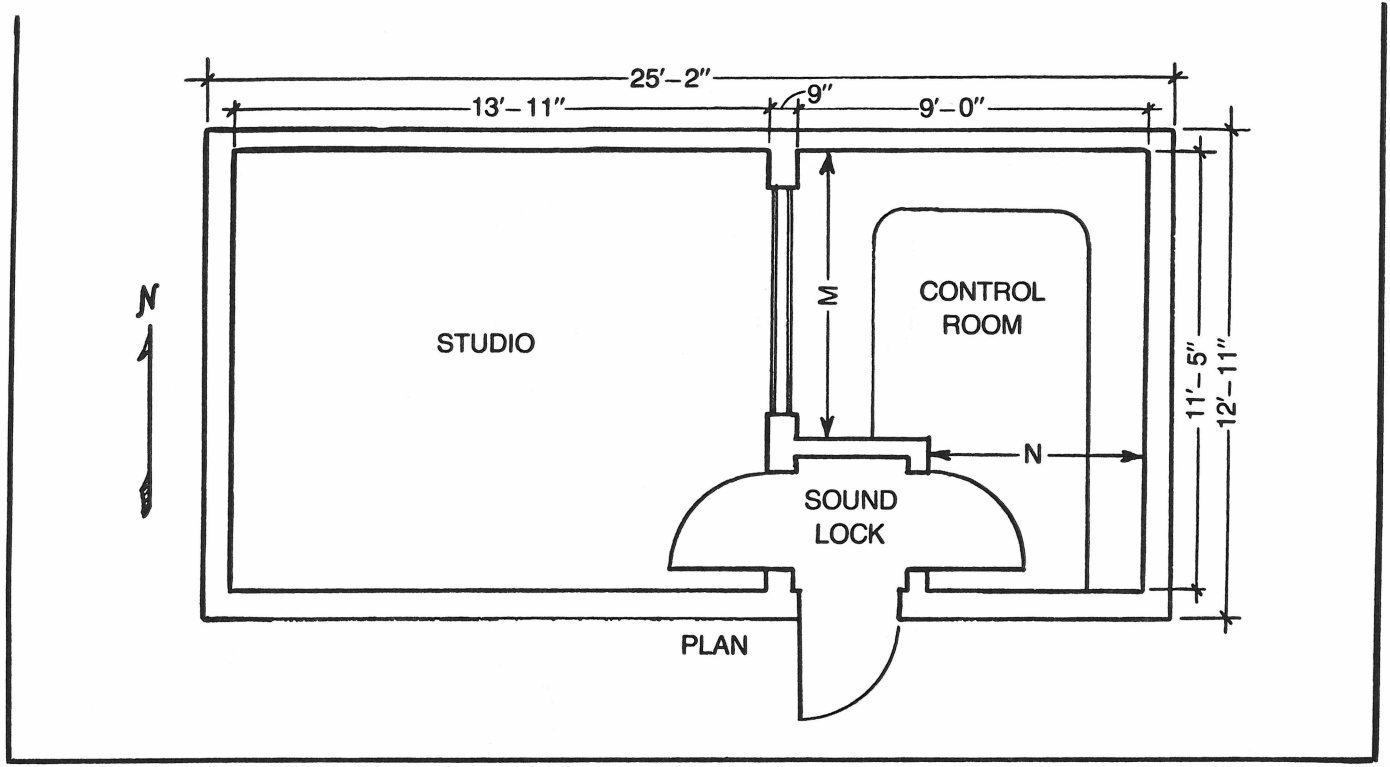


Fig. 3-1. Plan and elevation of a budget studio suite for the production of audiovisual materials. Because of limited floor space the control room "stands on end" to obtain the requisite room volume and room proportions.

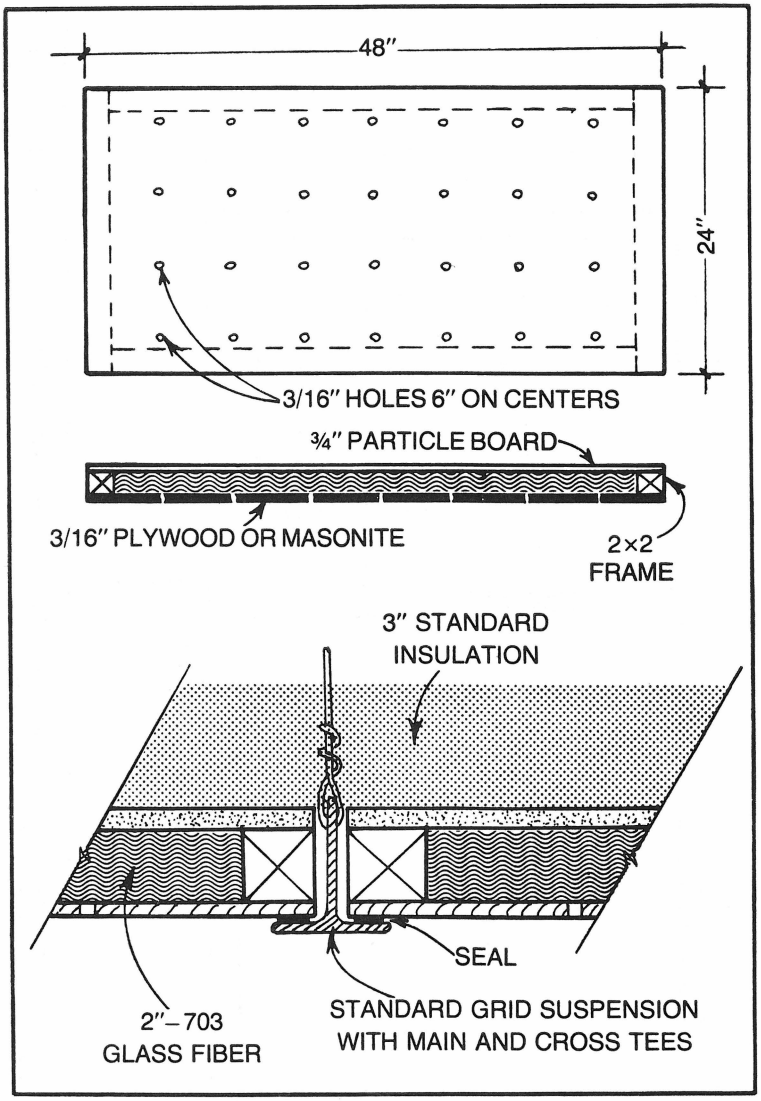


Fig. 3-2. Contracarpet panels are used in suspended ceiling of studio to compensate for unbalanced sound absorption characteristics of the carpet. They operate on the Helmholtz resonator principle.

scriptive, at least in this case where the contracarpet units are opposite the carpet. The contracarpet units are Helmholtz resonators about 2 inches thick fabricated in the familiar 24 inch × 48 inch size. The side facing the studio is 3/16 inch plywood or masonite perforated so that about 0.1 percent of

its area is holes. Holes of 3/16 inch diameter spaced 6 inches on centers give a perforation percentage of about the proper magnitude. The back (top) of each unit is of ¾ inch particle board (chipboard) which is somewhat denser than plywood. This particle board constitutes the acoustical ceiling which should be established 10 feet from the floor.

Sections not designated for contracarpet panels (Fig. 3-3) are filled with panels of ¾ inch particle board. Thus the acoustical ceiling height will vary by 2 inches from place to place. Both types of lay-in panels should be set on a continuous bead of non-hardening acoustical sealant on the suspended Tee frames. This will make a virtual hermetic seal between the studio and the "attic" space and reduce the possibility of rattles.

A 2 inch thickness of 3 pounds per cubic foot density glass fiber is jammed into the approximately 1¾ inch space determined by the 2 × 2s between the particle board and the perforated facing. (Throughout the book glass fiber of this

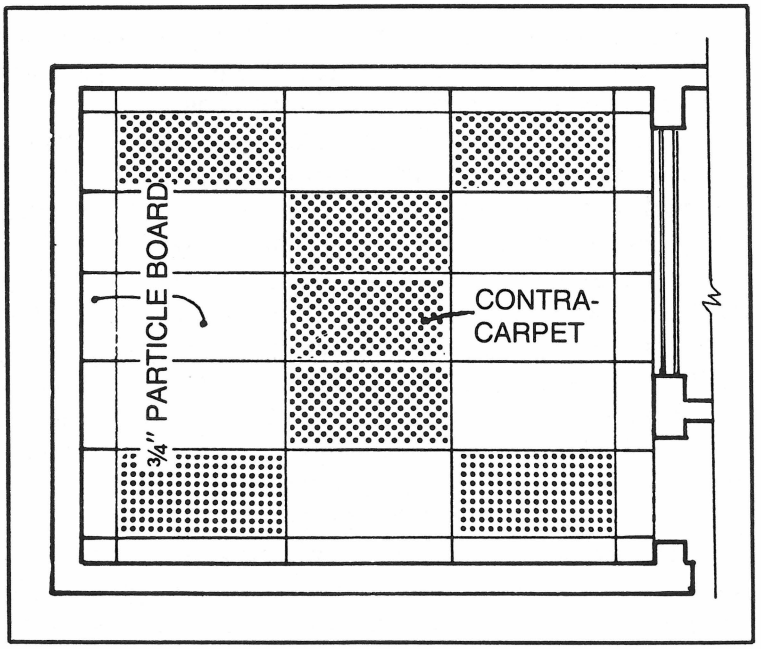


Fig. 3-3. Projected ceiling plan of studio showing location of the seven contracarpet panels. Frame sections not holding contracarpet units contain blank panels of ¾ inch particle board.

density will be repeatedly specified. Owens-Corning Type 703 is admirably suited. It is available in thicknesses of 1, 1½ & 2 inches, but building up a thickness of, say, two 2 inch thicknesses to obtain a 4 inch thickness is acoustically equivalent. (Johns-Manville has a product, Series 1000 Spunglass of 3 pounds per cubic foot density which is also acceptable.) This broadens the low frequency absorption peak. On top of the contracarpet and blank panels a blanket of common house insulation material of approximately 3 inch thickness is layed. If paper is attached, it should be placed downward. The purpose of the insulation layer is not so much to make the ceiling more impervious to sound as to deaden the space resonances in the "attic"

STUDIO WIDEBAND WALL UNITS

The third acoustical element in the studio (in addition to the carpet and contracarpet) is a series of identical wall units constructed as shown in Fig. 3-4. Each of these is basically nothing more or less than patches of 4 inch thick glass fiber of 3 pounds per cubic foot density, each having an acoustically effective surface of 12 square feet. These give essentially perfect sound absorption at 125 Hz and above.

The frame is of ordinary 1 inch lumber. The backing board of 3/16 inch or ¼ inch plywood or masonite is only to strengthen the frame and to make each unit a self-contained entity which can easily be mounted or removed. The cloth cover serves both as a cosmetic function and as an aid to contain the irritating glass fibers. This cloth should be treated with fire retardant chemicals for safety. Loudspeaker grille cloth would be ideal, although relatively expensive. Ordinary burlap or other open weave cloth of light weight can be employed. This fabric cover presents an excellent opportunity for color emphasis in the decor of the studio (pink noise will penetrate even a purple grille cloth!).

The method of mounting the wideband units to the wall will be left to the ingenuity of the builder, although a simple suggestion is shown at M in Fig. 3-4. If molding M is a strip running the length of a wall, the units may easily be positioned laterally anywhere on the wall. Further, a metal hook N on each front edge of the frame would allow reversal of the unit.

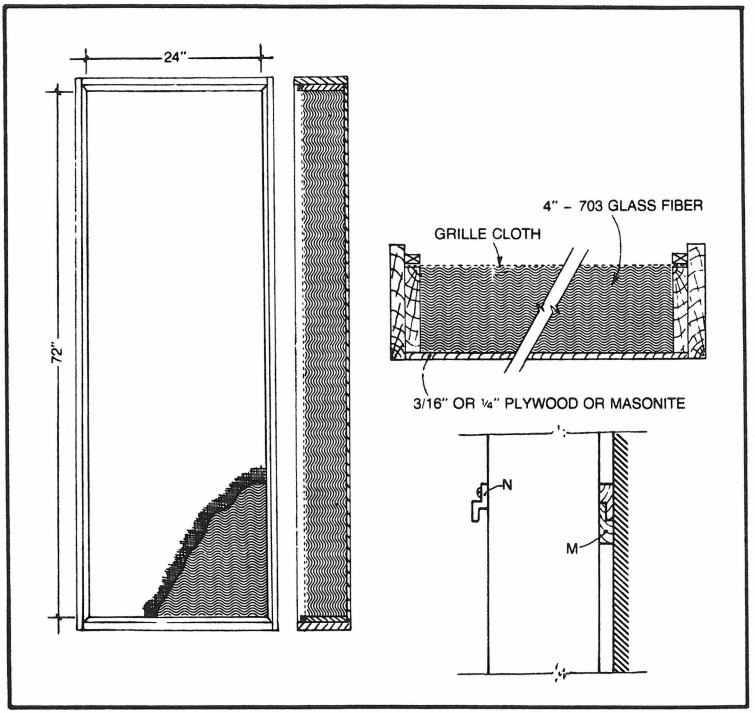


Fig. 3-4. Construction details of wall modules having wideband absorption characteristics. Used in both studio and control room.

In this way complete flexibility is realized: mounting or removing, positioning and reversing. With the soft side out, reverberation time is decreased. With the hard back exposed, it is increased, yet retains the advantage of a rectangular protuberance for diffusion of sound and for a measure of conrol of flutter echoes. There are limits to such adjustments of the acoustical properties of the room, but this degree of flexibility comes with negligible cost.

The suggested locations of the wideband modules on the walls of the studio are shown in Fig. 3-5. Three modules on the west wall oppose the window and the door on the east wall. The pair of modules on the north wall opposes bare areas on the south wall, and vice-versa. At first glance, Fig. 3-5 seems to show module opposite module, but remember that these wall elevations are the view one has facing the wall from inside the room and one must "do a 180°" between looking at the north wall and looking at the south wall.

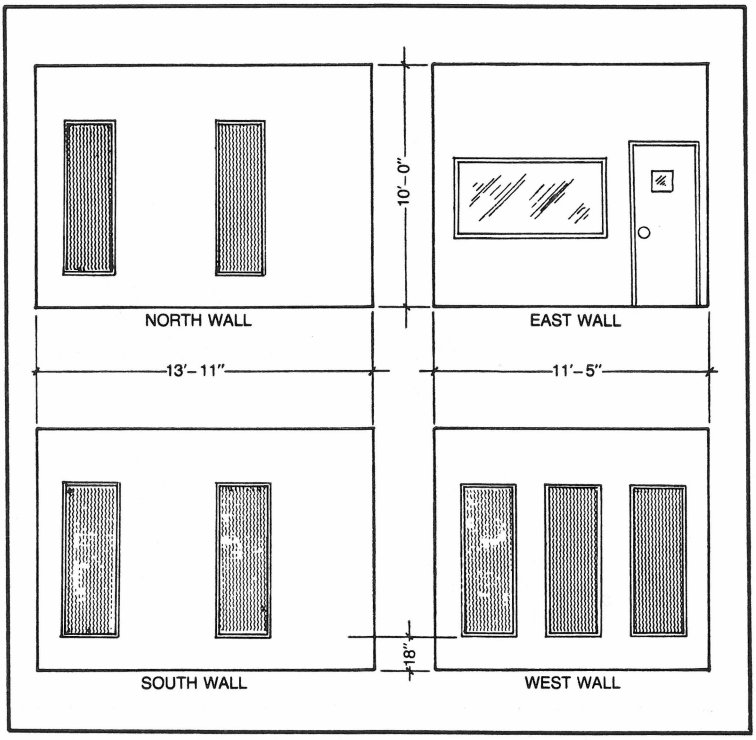


Fig. 3-5. Studio wall elevations showing location of wideband modules.

STUDIO DRYWALL

If a structural element contributes significantly to sound absorption in the studio, it must be considered as part of the acoustical treatment. The type of wall construction utilized in this studio is illustrated in Fig. 3-10. A layer of gypsum drywall panels is applied to one face of the wall and a double layer to the other face. As far as noise isolation is concerned, either face could be on the studio side. In the ensuing calculations it is assumed that the single layer of drywall is toward the studio and the control room although there would be only a minor difference in absorbing effect if it were the other way around. The gypsum panels on both sides of the wall vibrate as diaphragms on the cushion of air contained between them. The sound absorbed is greatest near the resonance frequency of the panel which, in turn, is a function of the depth of air space and mass per unit area of panel.

Absorption coefficients are available for ½ inch gypsum board on 2 × 4 framing which resonates at about 61 Hz. Using ⅝ inch instead of ½ inch and a nominal air space of 8 inches instead of 4 inches shifts the resonance frequency down to about 38 Hz. This reduces the absorption coefficients in the 125 Hz-4 kHz range somewhat.

In Table 3-1, however, the available published values for the ½ inch thickness and 4 inch airspace are used to avoid complicating the procedure. It is to be noted that both the contracarpet and blank panels of the ceiling contribute slightly to low frequency absorption as diaphragms, over and above the contracarpet Helmholtz resonator effect. This would be in the direction of compensating for the fact that the wall used differs from the one to which the coefficients strictly apply.

STUDIO COMPUTATIONS

A bit of figuring gives us the required data for the studio: surface area = 823 square feet, volume = 1585 cubic feet. With this we can enter the *sanctum sanctorum* of the *Eyring equation* to determine the absorption required to realize our desired reverberation time, which is 0.3 second. The *Eyring equation* is:

$$T_{60} = \frac{0.049V}{-S \log_e(1-a)}$$

where

T_{60} = reverberation time, seconds
V = volume of studio, cubic feet
S = surface area of studio, square feet
a = average absorption coefficient

The above equation is transposed:

$$\log_e(1-a) = \frac{0.049V}{(-S)(T_{60})}$$

Substituting area, volume and desired reverberation time we get:

$$\log_e(1-a) = \frac{(0.049)(1585)}{-(823)(0.3)} = -0.31456$$

Pushing the e^x key on the trusty calculator:

$$(1-a) = 0.73011$$
$$-a = 0.73011 - 1$$
$$a = 0.2699$$

Table 3-1. Studio Calculations.

SIZE.....11′–5″ × 13′ – 11″ × 10′–0′ ceiling
FLOOR.....Heavy carpet and pad
CEILING.....7 – 2′ × 4′ contracarpet modules (See Fig. 3-3)
WALLS.....7 – 2′ × 6′ wideband modules (See Figs. 3-4 & 3-5)
SURFACE AREA.....823 square feet.
VOLUME.....1,585 cubic feet

Material	S Area Sq. Ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	159.	0.08	12.7	0.24	38.2	0.57	90.6	0.69	109.7	0.71	112.9	0.73	116.1
Drywall	665.	0.10	66.5	0.08	53.2	0.05	33.3	0.03	20.0	0.03	20.0	0.03	20.0
Contracarpet	56.	0.90	50.4	0.54	30.2	0.30	16.8	0.16	9.0	0.12	6.7	0.10	5.6
Wideband Modules	84.	0.99	83.2	0.99	83.2	0.99	83.2	0.99	83.2	0.99	83.2	0.99	83.2
Total sabins, Sa			212.8		204.8		223.9		221.9		222.8		224.9
Average absorption coefficient a = Sa/823			0.259		0.249		0.272		0.270		0.271		0.273
Reverberation time, seconds (Eyring)			0.31		0.33		0.30		0.30		0.30		0.30

This appears to be reasonable because the average absorption coefficient of most small studios is around 0.25 to 0.30. The next step is to determine the number of absorption units in the room to give us the desired T_{60}, 0.3 second.

Total absorption units = (S) (a)
= (823) (0.2699)
= 222 sabins.

Now, what does this mean? Simply that 222 square feet of perfect absorber (a = 1.00) in the room would yield the desired 0.3 second reverberation time. The original perfect

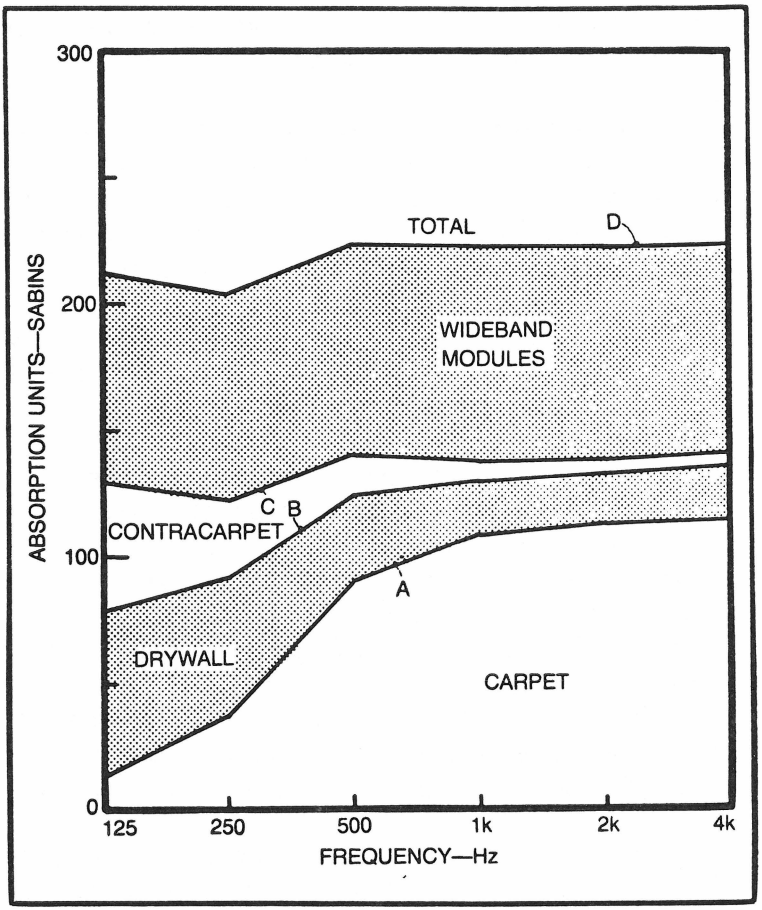


Fig. 3-6. Relative sound absorption contributions of various elements used in treating the studio. Note that the contracarpet panels and drywall construction compensate for the low frequency deficiency of the carpet.

absorber conceived by pioneer acoustician Wallace Sabine was an open window.

All the sound falling on an open window is surely absorbed as far as the room is concerned, but the practical absorbing materials we have to work with are something less than perfect, especially if you add the requirement, "throughout the range of audible frequencies."

The room computation process requires some of what is euphemistically called *engineering estimating*. This is nothing more than guessing, but engineers become better and better guessers as their years of experience pile up. The guessing comes in deciding how much of what kind of absorbing materials will give the 222 sabins for each frequency point throughout the band.

Carpet is specified, so there is no guessing about that. The carpet area is entered in Table 3-1. The absorption coefficients for the carpet selected are entered for each frequency. By multiplying the carpet area by each coefficient, the absorption in sabins is found for each frequency and entered in Table 3-1.

By plotting the carpet absorption points in Fig. 3-6, graph A is obtained. As drywall is the other fixed element, its absorption is calculated for each frequency and entered in Table 3-1. By adding carpet and drywall absorption and plotting the resulting sums on Fig. 3-6, graph B is obtained.

The drywall partially makes up for lack of carpet absorption in the low frequencies, but not enough. A few trial calculations show that seven contracarpet ceiling units give us graph C which is reasonably horizontal at roughly 140 sabins. This must be raised to the vicinity of 225 sabins and it is the function of the seven wideband wall modules (essentially perfect absorbers in the 125 Hz-4 kHz range according to the manufacturer's measurements) to do this (graph D of Fig. 3-6). The wiggles of graph D have only a minor effect on reverberation time.

Table 3-1 shows that reverberation time varies only from 0.30 to 0.33 second as a result of the fluctuations of graph D, Fig. 3-6. Our precision is not good enough to justify pursuing such calculations further. The calculated studio reverberation

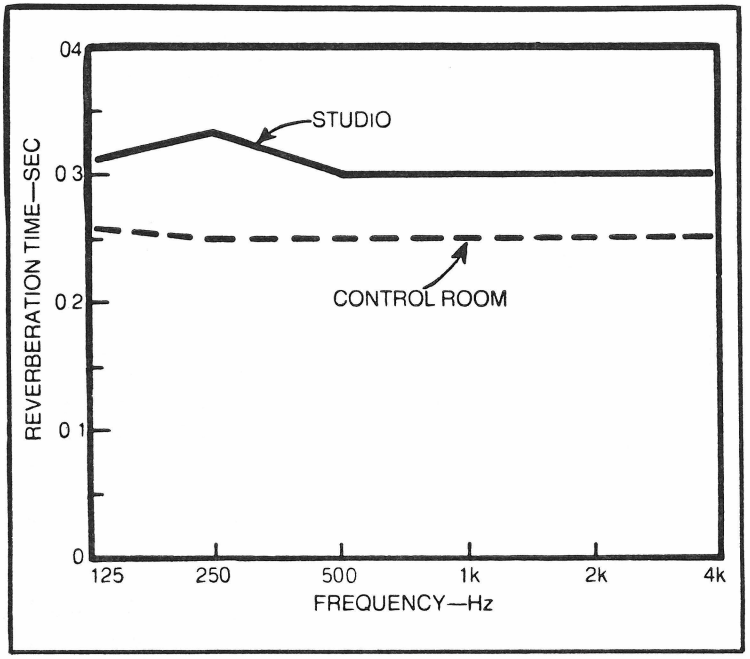


Fig. 3-7. Computed reverberation time characteristics of the studio and control room. The evaluation of studio sounds monitored in the control room is aided by having lower reverberation in the control room.

time variations with frequency are shown graphically in Fig. 3-7.

CONTROL ROOM TREATMENT

The control room is generally admitted to be a work room, especially in audiovisual work. For this reason there is usually a minimum amount of opposition to vinyl tile floors which are especially practical for rolling equipment around the room.

Reverberation time for a control room should be somewhat shorter than that of the studio being monitored. The reverberation associated with studio sounds reproduced on the monitoring loudspeaker are then heard without being masked by control room reverberation. Listening rooms require relatively uniform reverberation time with frequency as do studios. Solving the Eyring equation for average absorption, given a control room volume of 1243 cubic feet, surface area of 742 square feet and reverberation time of 0.25 second,

Fig. 3-8. Wall elevations of control room showing placement of standard suspended ceiling, 2' x 6' wideband wall modules and acoustical tile.

we get an average absorption coefficient a = 0.280 and a total absorption Sa = 208 sabins.

CONTROL ROOM CEILING TREATMENT

A standard suspended ceilng is specified to oppose the reflective vinyl floor. This ceiling is dropped 16 inches below the acoustical ceiling of drywall which is at a 13 foot-9 inch height (Fig. 3-8).

The distinction must always be made between the visual and the acoustical dimensions of a room. The space between the suspended lay-in ceiling and the solid ceiling at a 13 foot-9 inch height is acoustically active.

For example, there are specific resonance effects between the lay-in panels and the air space above them which result in good low frequency absorption. This makes the overall absorption relatively uniform with frequency (Fig. 3-9E).

By using the usual soft fiber lay-in panels with NRC (*noise reduction coefficient*) rating between 0.75 and 0.85, the sus-

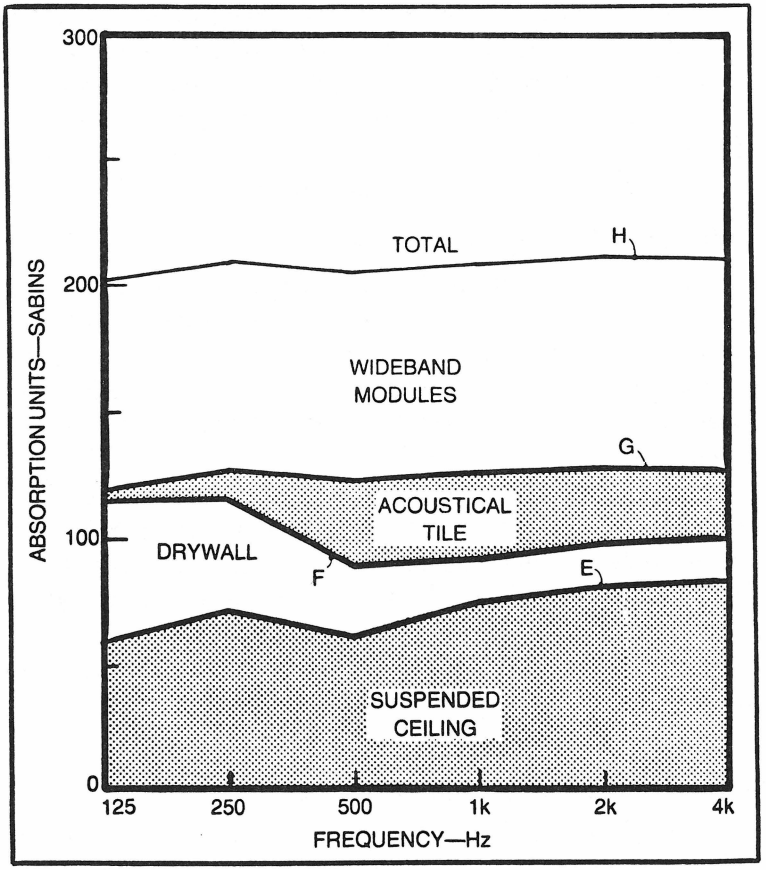


Fig. 3-9. Relative sound absorption contributions of the various elements used in treating the control room. The unavoidable absorption of the drywall construction used results in too much low frequency absorption which is corrected by the acoustical tile.

pended ceiling absorption coefficient varies between 0.65 and 0.92 (Table 3-2). By using the 16 inch drop instead of some other distance, the coefficients supplied by the manufacturer can be used with some confidence. Deviations from this standard 16 inch drop results in no known coefficients to depend upon.

CONTROL ROOM DRYWALL

The diaphragmatic absorption of gypsum board surfaces must also be figured into the control room. The floor is vinyl tile covering concrete, so that is not included. Because of the complicating effect of the suspended ceiling we shall neglect the drywall ceiling above it. The walls alone (including doors and window which also act as diaphragms) total 561 square feet. The sum of drywall and suspended ceiling absorption from Table 3-2 is plotted as graph F in Fig. 3-9. Slight overcompensation now prevails in the low frequencies.

CONTROL ROOM ACOUSTICAL TILES

Common acoustical tile is probably the most abused and misused product in the annals of sound treatment because people expect too much of it. However, it is an excellent product if properly used, inexpensive and easy to apply. It is characterized, as is carpet, by good high frequency absorption, but little at low frequencies.

This is exactly what is needed in the present case. The addition of 42 acoustical tiles 12 inches × 12 inches × ¾ inch to the control room brings the absorption to an approximately uniform 125 sabin level throughout the frequency range of interest as shown by graph G of Fig. 3-9. It is desirable not to have all of a given type of absorber in a room active in only one mode. Figure 3-8 shows the acoustical tile acting on both the N-S and E-W modes of the room.

CONTROL ROOM WIDEBAND MODULES

The 125 sabin level of graph G in Fig. 3-9 is about 83 sabins below the 208 sabins required for a reverberation time of 0.25 second. Seven 2 foot × 6 foot wideband modules provide this 83 sabins, bringing the total absorption up to graph H of Fig. 3-9 which hovers close to the 208 sabin goal.

Table 3-2. Control Room Calculations.

SIZE ..... 9'–0" × 11'–5" × 13'–9" ceiling
FLOOR ..... Vinyl tile
CEILING ..... Standard suspended ceiling, panels NRC 0.75–0.85
WALLS ..... 42 acoustical tiles 12" × 12" × ¾" (Fig. 3-8)
7 Wideband modules 2' × 6' (Fig. 3-8)
SURFACE AREA ..... 742 sq. ft.
VOLUME ..... 1,243 cu. ft.

Material	S Area Sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Suspended ceiling	90.4	0.65	58.8	0.78	70.5	0.67	60.6	0.82	74.1	0.89	80.5	0.92	83.2
Drywall	561.	0.10	56.1	0.08	44.9	0.05	28.1	0.03	16.8	0.03	16.8	0.03	16.8
Acoustical tile	42.	0.09	3.8	0.27	11.3	0.78	32.8	0.84	35.3	0.72	30.2	0.64	26.9
Wideband modules	84.	0.99	83.2	0.99	83.2	0.99	83.2	0.99	83.2	0.99	83.2	0.99	83.2
Total Sabins, Sa			201.9		209.9		204.7		209.4		210.7		210.1
Average absorption coefficient a = Sa/742		0.272		0.283		0.276		0.282		0.284		0.283	
Reverberation time, seconds (Eyring)		0.26		0.25		0.25		0.25		0.25		0.25	

The control room reverberation time of Table 3-2 is compared graphically to that of the studio it serves in Fig. 3-7.

A grand total of 14 of the 2 foot × 6 foot wideband modules detailed in Fig. 3-4 are now required, seven for the studio and seven for the control room. Some economy in effort and expense should result from mass production.

NOISE FACTORS

The level of noise outside the studio suite and background noise standards set for inside the studio determine the type of wall construction. A nearby printing press, buzz saw or other such noise makers may require exceptional measures.

However, if this is to be a budget studio, wall construction costs must be kept in line. Most small organizations attracted by the budget approach are willing to do some horse trading. If the printing press operates only part time, the audiovisual people can schedule their recording time accordingly. Perhaps a flashing red light at the buzz saw during a take would suggest to the carpenter that this is a good time for a cup of coffee.

Having to repeat three takes a year because of low-flying helicopters is far cheaper than building a building within a building to get 80 dB transmission loss.

For this budget studio complex an economical wall that offers good protection (about STC 50) against outside noise is illustrated in Fig. 3-10. The staggered stud principle gives two independent walls attached only at the periphery. To the 2 × 4 studs 16 inches on centers on a 2 × 8 plate is nailed a single layer of ⅝ inch gypsum board on one side and a double layer of ⅝ inch gypsum board on the other. Thermal type insulation of at least a 3 inch thickness minimizes resonances in the space between the walls. The effectiveness of even this staggered construction depends upon tight sealing. To assure this, a bead of non-hardening acoustical sealant should be run around all intersections of walls with ceiling, floor and other walls. All exterior walls and the wall separating the control room from the studio should be of the construction shown in Fig. 3-10. The north and east walls of the sound lock and the

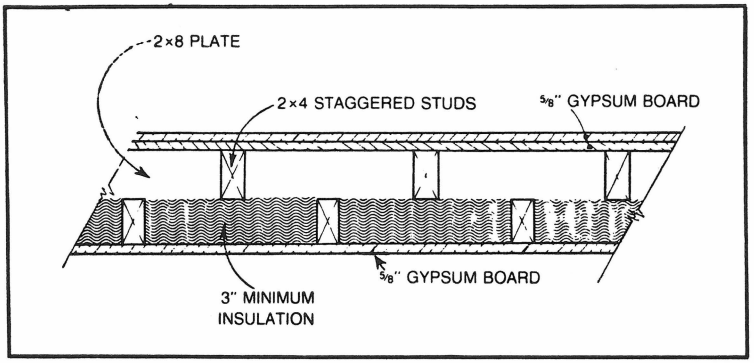


Fig. 3-10. Constructional details of studio and control room walls to protect against external noise and to provide adequate isolation between control room and studio.

sound lock ceiling may be of normal single stud construction with single layers of gypsum board. The control room ceiling at a 13 foot-9 inch height is standard ⅝ inch gypsum board on frame construction with the suspended ceiling dropped 16 inches below this.

Chapter 4

Studio Built In a Residence

Features: Polys on the ceiling, A/C duct layout for minimum noise and crosstalk.

Building a studio and control room in the average modern single family dwelling presents major problems: thin walls, low ceilings and limited floor area. In this case, however, the residence is not average. It has concrete floors, stone and brick walls and ample headroom. Needless to say, it is located outside the United States. There are a number of lessons to be learned from this case, however, and the solutions to specific problems to be considered are quite applicable to other situations.

FLOOR PLAN

The *as found* floor plan is shown in Fig. 4-1. Walls are either 17 inch thick stone, 10 inch thick brick or glass. The first two warm the acoustician's heart but the last one is mentally placed high on the *get rid of it* list. The dining and living rooms are separated by a 4 foot barrier. The floor of the dining room is 8 inches lower than that of the living room. This is the house that is available. Can it be converted into an effective studio and control room without major alterations?

Figure 4-2 illustrates the changes made. Basically, the living room was visualized as the studio and the dining room as

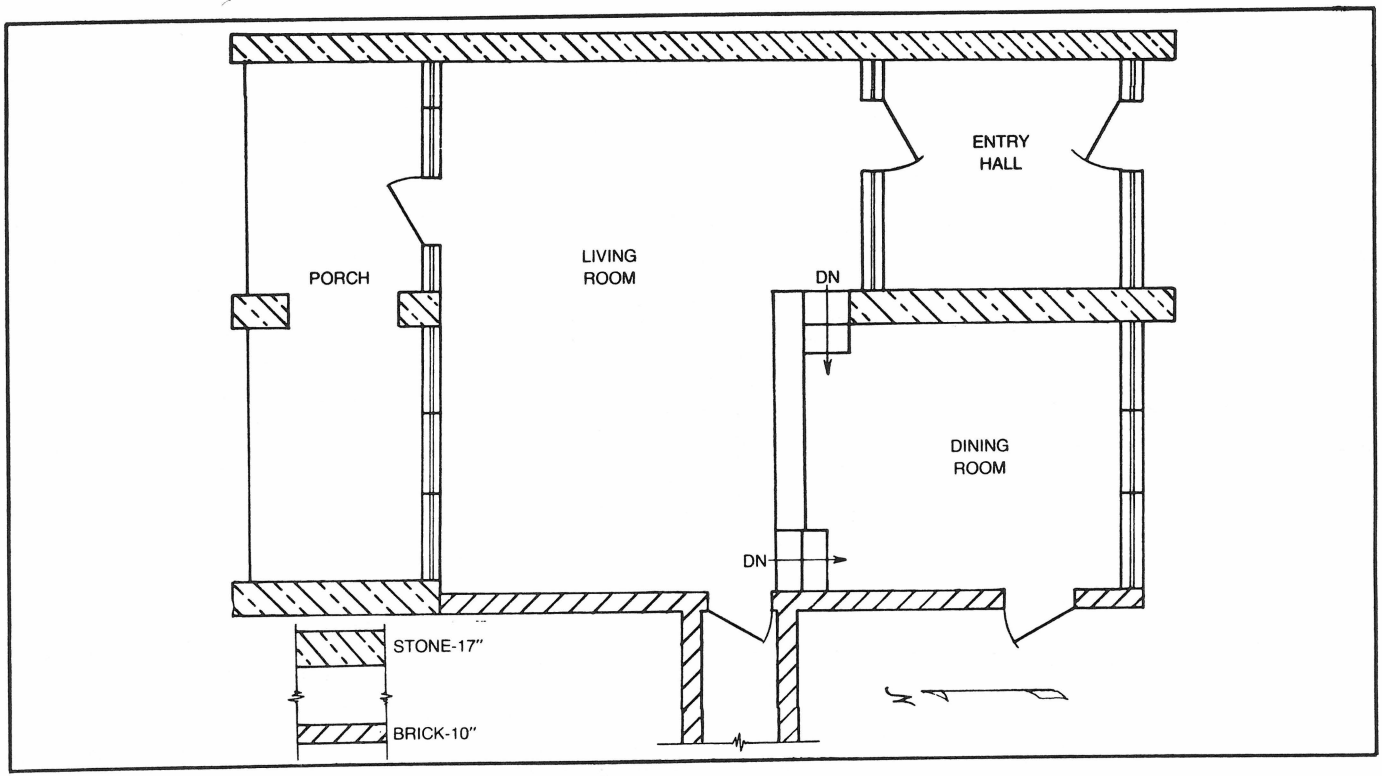


Fig. 4-1. Floor plan of residence before conversion into studio complex.

the control room. This required pouring enough concrete into the dining room to bring its floor up flush with the living room floor. The north wall of glass was eliminated and a 10 inch thick brick wall established at the outer center column, enlarging the width of the studio more than 6 feet. A wall of brick to hold the observation window was placed at a 45 degree angle to give the control operator a good view into the studio and to provide certain acoustical advantages in both rooms. This angled wall makes the control room unsymmetrical which would be considered a disadvantage in a professional recording studio. However, in the present case the advantages outweigh the disadvantages.

A sound lock with brick walls was located as shown in Fig. 4-2 and the inner glass wall of the entrance hall was eliminated in the process. The external glass wall of the entrance hall survived as the entrance hall function remained unchanged. Door A in the west wall of what is now the control room was bricked up. This routed all traffic between the studio and other parts of the house either through door B in the west wall or by outdoor paths. After objections were voiced by the consultant at having a second door into the control room, it was left to the client to either establish a second sound lock in the west hallway or route all traffic outdoors and through the entrance hall. As this residence is in a tropical country, this latter should create no major problems.

The space in the sharp angled northwest corner of the control room was made into a closet for the storage of tape stock, recorded tape library, etc. Note also that the operator's position is set back at least 5 feet from the glass surface. This is to give the operator an acceptable angle with the monitoring loudspeaker(s) and an acoustically better position for critical listening. The pillar in the studio area was slated for removal if not loadbearing. However, it could remain, causing some inconvenience but little adverse acoustical effect. The added studio volume obtained by pushing out the studio north wall is very important acoustically.

STUDIO TREATMENT

Stepping into the untreated studio of Fig. 4-2, one is met by a great expanse of brick and stone walls, concrete floor,

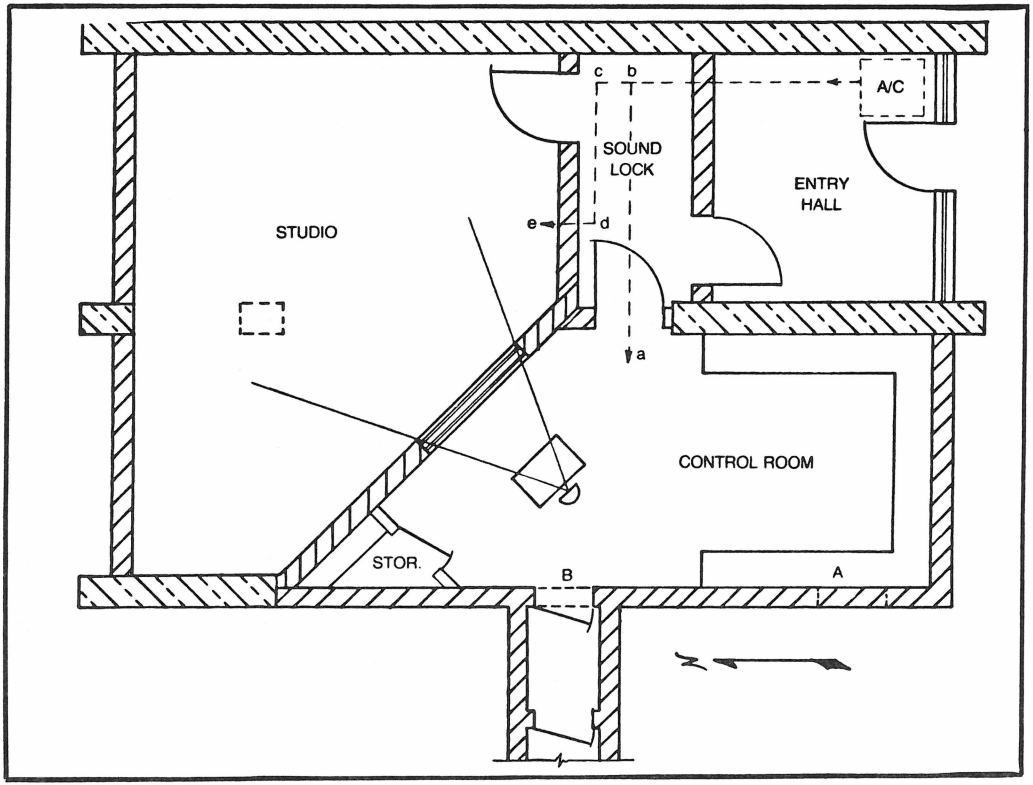


Fig. 4-2. Floor plan of residence converted into studio and control room with sound lock.

glass observation window and the wooden underside of the roof. At this time one cannot escape the thought that it would make an excellent reverberation chamber. The first step in making a studio out of it is to determine the correct number of absorption units (sabins) required. Measurements reveal a volume of 4,614 cubic feet and an inside surface area of 1,597 square feet.

What reverberation time should be adopted? As both music and speech are to be recorded in this room, a compromise value of about 0.4 second seemed in order.[2] Cranking these values of volume, area and reverberation time into the Eyring equation, an average absorption coefficient of 0.298 comes out. Multiplied by the surface area of 1,597 square feet it is computed that 476 absorption units, or sabins, are required. This is a point of departure and a start in building Table 4-1.

Ceiling

At the high frequencies the carpet is a dominant factor, supplying almost half the required absorption while contributing practically nothing at the low frequencies (Fig. 4-3). This poses the classical problem of introducing other absorbing elements which have the opposite effect. This time semicylindrical panel units are chosen over the Helmholtz resonator approach. Such cylindrical units on the studio ceiling between the concrete roof beams, as shown in Figs. 4-4 and 4-5, will contribute in the following ways:

- They augment a thin roof in protecting against outside noise.
- They act as excellent diffusers of sound in the studio.
- They absorb sound in the studio in a way which tends to compensate for the carpet deficiencies at low frequencies.

These cylindrical elements are basically a thin skin of 3/16 inch plywood or masonite stretched over bulkheads cut as segments of a circle. The radius and chord of this segment are carefully adjusted so that the arc is 48 inches—the standard width of plywood and masonite. The skin of these cylindrical elements, which vibrates vigorously in response to sound in

Table 4-1. Studio Calculations

SIZE ..... 18′ – 4″ × 23′ – 1″ (corner cut) × 13′ – 3″ ave. ceiling ht.
FLOOR ..... Carpet
CEILING ..... Semicylindrical plywood elements
WALLS ..... 16 2′ × 8′ wideband modules
SURFACE AREA ..... 1,597 sq. ft.
VOLUME ..... 4,614 cu. ft.

Material	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	349	0.05	17.5	0 15	52.4	0.30	104 7	0.40	139.6	0.50	174.5	0.60	209.4
Semicylindrical plywood	328	0.45	147.6	0.57	187 0	0 40	131.2	0.25	82.0	0.20	65.6	0.20	65.6*
Wideband Modules	256	0.99	253.4	0.99	253.4	0.99	253.4	0.99	253 4	0.99	253.4	0.99	253.4
Total sabins Sa			418.5		492.8		489.3		475.0		493.5		528.4
Average absorption coefficient, a = Sa/1597			0.262		0.309		0.306		0.297		0.309		0.331
Reverberation Time, sec. (Eyring)			0.466		0.383		0.388		0.402		0.383		0.352

* Mankovsky

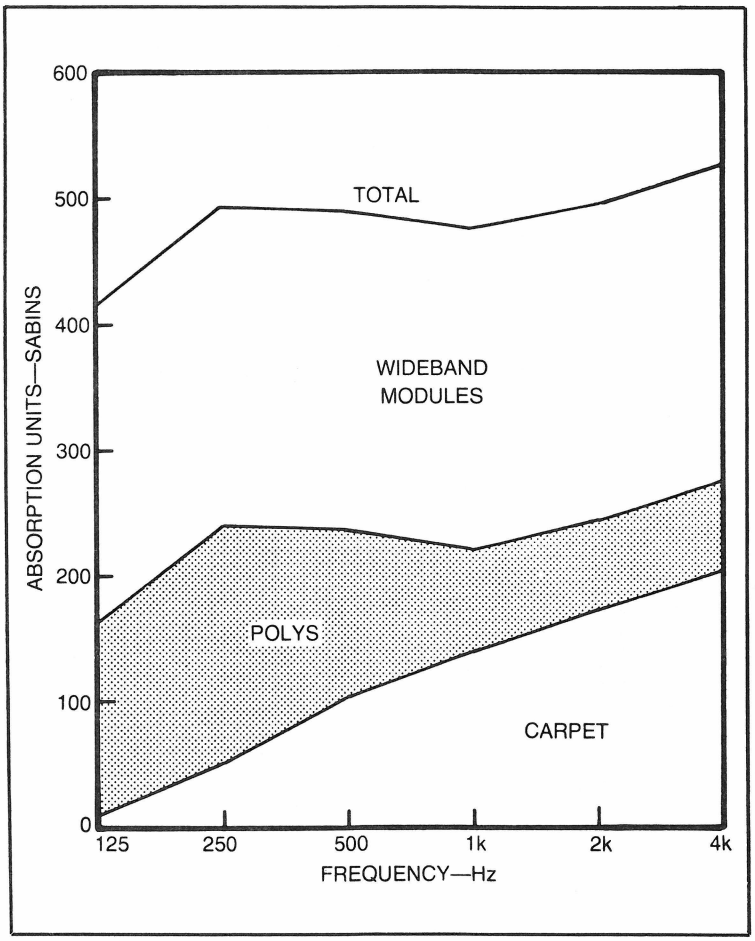


Fig. 4-3. Absorption contributions of the three materials used in the studio. The semicylindrical plywood ceiling elements compensate for the carpet deficiencies quite well, except at 125 Hz.

the room, must not rattle. As protection against rattles a bead of non-hardening acoustical sealant, or better yet, a thin strip of felt, is applied to the edge of each bulkhead before the skin is bent over them and nailed in place. The functioning and construction of such cylindrical elements (often called *polycylindrical diffusers* or *polys*) as well as absorption coefficients for units of different sizes are detailed in a companion volume[3]. The space within the semicylindrical units may be stuffed with common thermal type mineral wool or glass fiber.

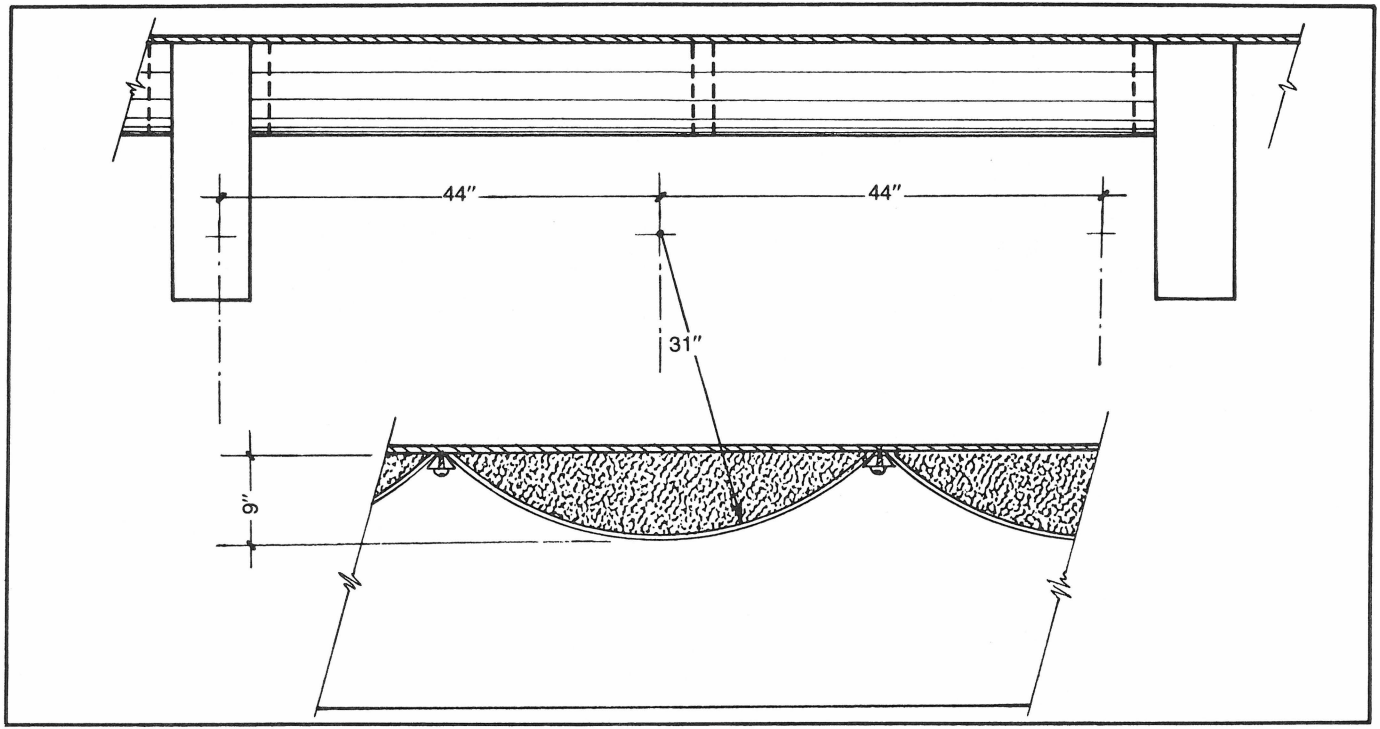


Fig. 4-4. Construction features of the semicylindrical plywood elements mounted on the ceiling between the concrete roof beams. The radius and chord are chosen so that the arc is 48 inches—the plywood width.

Walls

The compensation of carpet deficiencies by the cylindrical elements, as shown in Fig. 4-3, is quite good except for 125 Hz and below. The effects of this on reverberation time will be considered more fully later. To approach the required 476 sabins, about 256 square feet of wideband absorber are required. This absorption can be supplied by 4 inches of 703 glass fiber or its equivalent. The suggested wall modules have these advantages:

- Contributing to the diffusion of sound in the room, thus making microphone placement less critical.
- Allowing for later trimming of acoustics if measurements indicate the necessity of this.
- Being used in both studio and control room with resulting economies.

A total of sixteen 2 foot × 8 foot units provide the required 256 square feet. They are positioned on the walls as shown in Fig. 4-6.

STUDIO REVERBERATION TIME

Table 4-1 brings together the specific absorption contribution of the carpet, the cylindrical ceiling elements and the 16 wall modules at each frequency. The resulting reverberation time is plotted in Fig. 4-7. There are some deviations from the goal of 0.4 second. The slight drooping at high frequencies is no problem. It is actually preferred by many.

The bass rise shall be examined a bit more closely. BBC engineers have looked into this with characteristic thoroughness[10]. They found that the degree of impairment of speech quality by such bass rise was affected by the voice of the person speaking, the type of microphone used and the distance between the speaker and the microphone (which determines the relative effect of room reverberation). As a tentative conclusion for the average situation, they suggested that a rise of reverberation time at 125 Hz over the 500 Hz value of no more than roughly 20 percent should be allowed for voice work. The rise in Fig. 4-7 is very close to this amount. They suggest that no more than about a 90 percent rise of the 63 Hz reverberation time over that at 500 Hz be allowed.

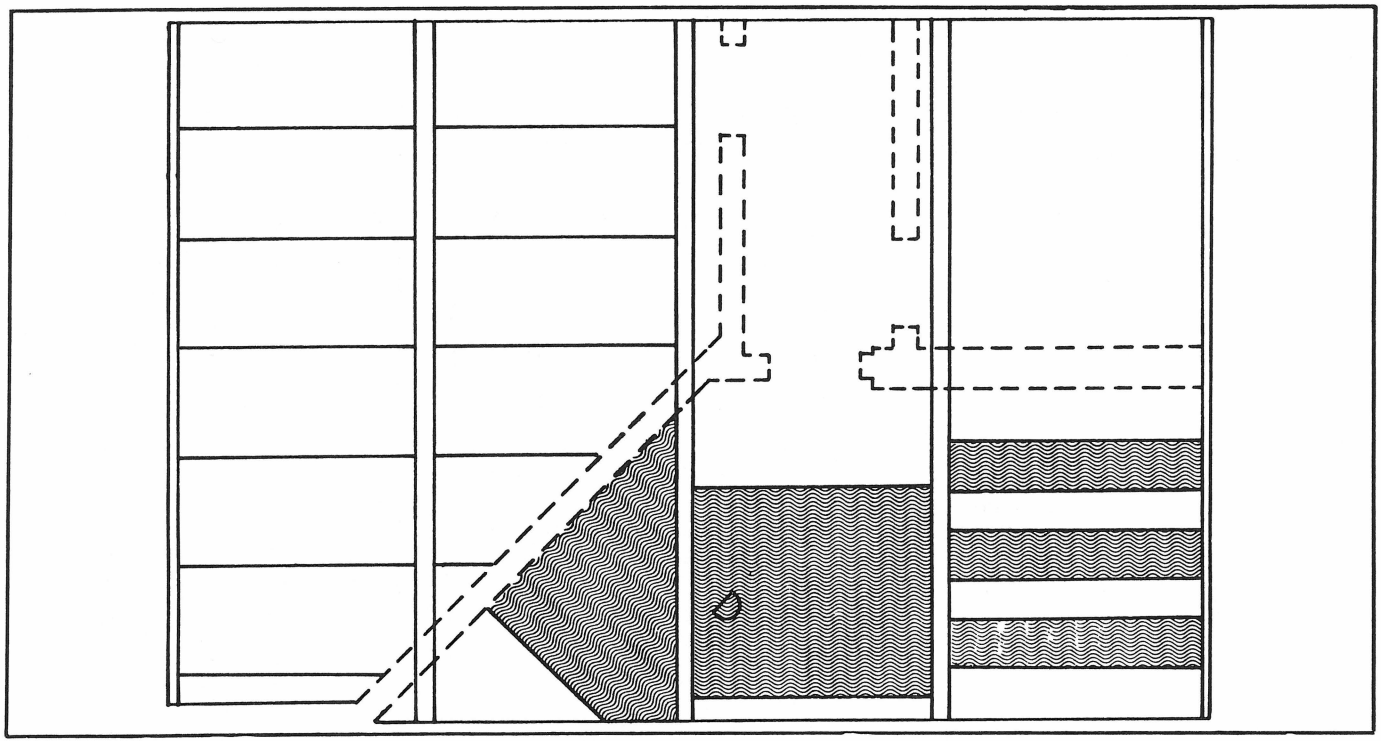


Fig. 4-5. Projected ceiling plan for both studio and control room showing placement of semicylindrical plywood elements in the studio and patches of 4 inch glass fiber in the control room.

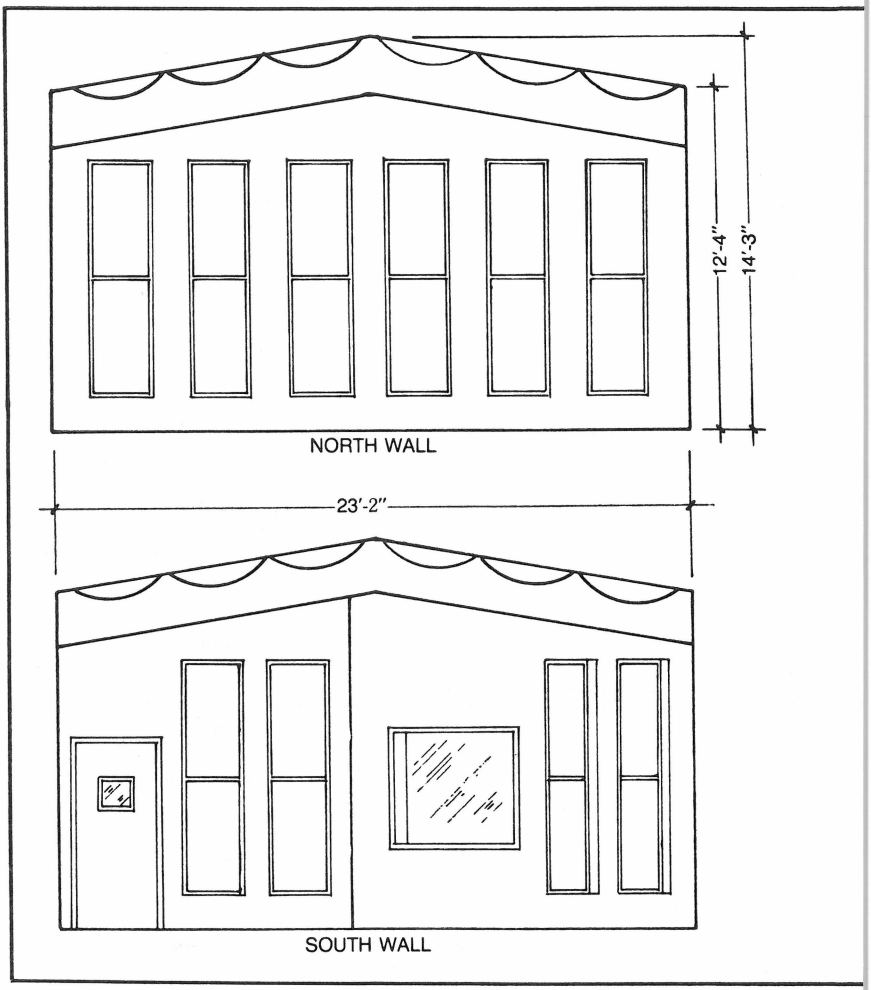
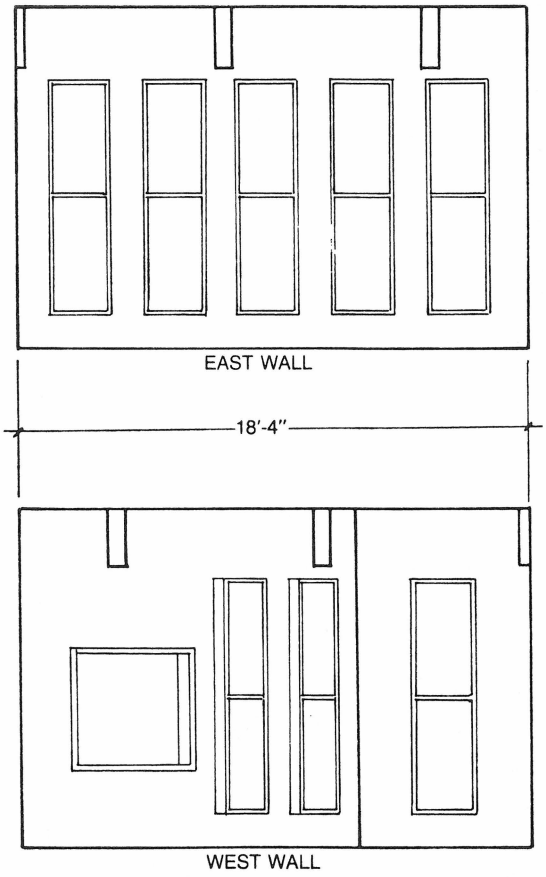


Fig. 4-6. The four wall elevations of the studio showing placement of the wide-band absorbing modules.

Table 4-1 stops at 125 Hz but we know that absorption of both ceiling elements and wall modules falls off below 125 Hz. It seems unlikely that the reverberation time at 63 Hz, however, would be greater than the allowed approximate 0.7 second.

CONTROL ROOM TREATMENT

Deciding in favor of a hard floor (concrete, vinyl tile, parquet wood, etc.) reduces the treatment of the control room



to a single type of absorber, 4 inches of 703. Table 4-2 combines the 124 square feet of 703 assigned to the ceiling, the 184 square feet in wall modules on the east and west wall and 48 square feet in wall modules on the south wall. It treats the 356 square feet total together. This total area, of course, was calculated from the Eyring equation by inserting the desired reverberation time of 0.35 second, the volume of 2,964 cubic feet and the area of 1,290 square feet. Turning the crank gives an average absorption coefficient of 0.275 and a total of 355 sabins.

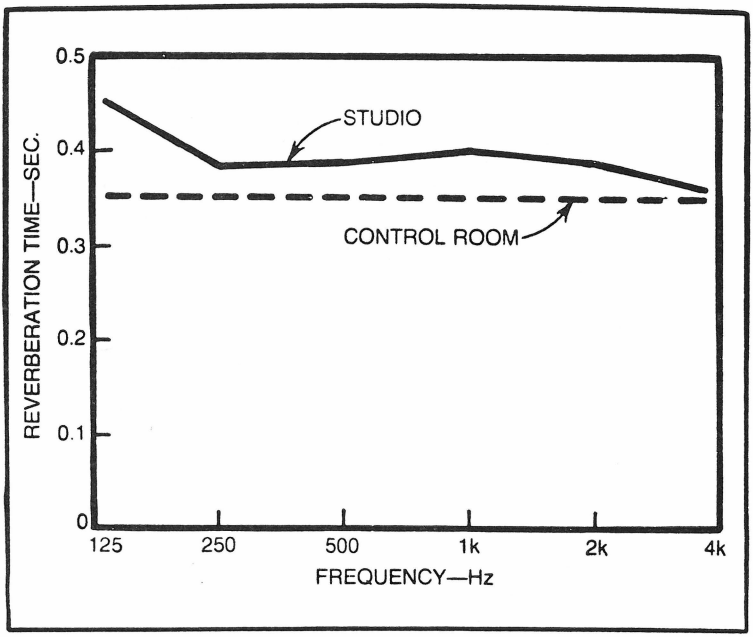


Fig. 4-7. Reverberation time characteristics of studio and control room. The bass rise in computed studio reverberation is within BBC limits.

Ceiling Treatment

First, it is important that the ceiling over the operator be absorbent. The operator's position is indicated in Fig. 4-5 by the same symbol used in Fig. 4-2. It should be remembered that this ceiling slopes as shown in Fig. 4-6 which is favorable for the floor-ceiling mode. The bare ceiling area must be distributed for the best diffusion effect and the pattern of Fig. 4-5 was selected.

The 4 inches of 703 is held to the ceiling in the manner detailed in Fig. 4-8. There is really considerable freedom in

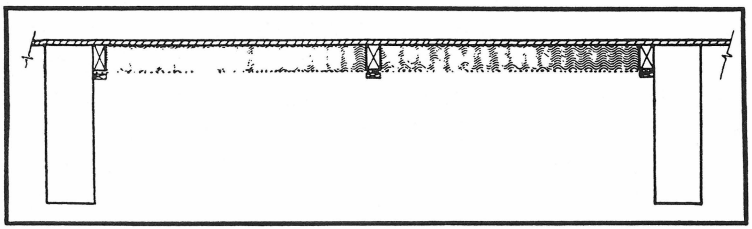


Fig. 4-8. Method of mounting the 4 inch glass fiber on the ceiling of the control room.

Table 4-2. Control Room Calculations

SIZE.....11′ – 0″ × 16′ – 2″ × 13′ – 4″ ave. ceiling ht.
FLOOR.....Vinyl tile or concrete or parquet
CEILING.....Patches of 4″ 703 glass fiber
WALLS.....10– 2′ × 8′ and 6 – 2′ × 6′ wideband modules
SURFACE AREA.....1,290 sq. ft.
VOLUME .....2,964 cu. ft.

Material	S Area sq. ft.	125 Hz a	125 Hz Sa	250 Hz a	250 Hz Sa	500 Hz a	500 Hz Sa	1 kHz a	1 kHz Sa	2 kHz a	2 kHz Sa	4 kHz a	4 kHz Sa
Ceiling: 703 glass fiber	124												
E and W walls wideband mods	184												
S wall wideband modules	48												
Total area	356	0.99	352.4	0.99	352.4	0.99	352.4	0.99	352.4	0.99	352.4	0.99	352.4
Total sabins, Sa			352.4		352.4		352.4		352.4		352.4		352.4
Average absorption coefficient, a=Sa/1290			0.273		0.273		0.273		0.273		0.273		0.273
Reverberation time, sec. (Eyring)			0.353		0.353		0.353		0.353		0.353		0.353

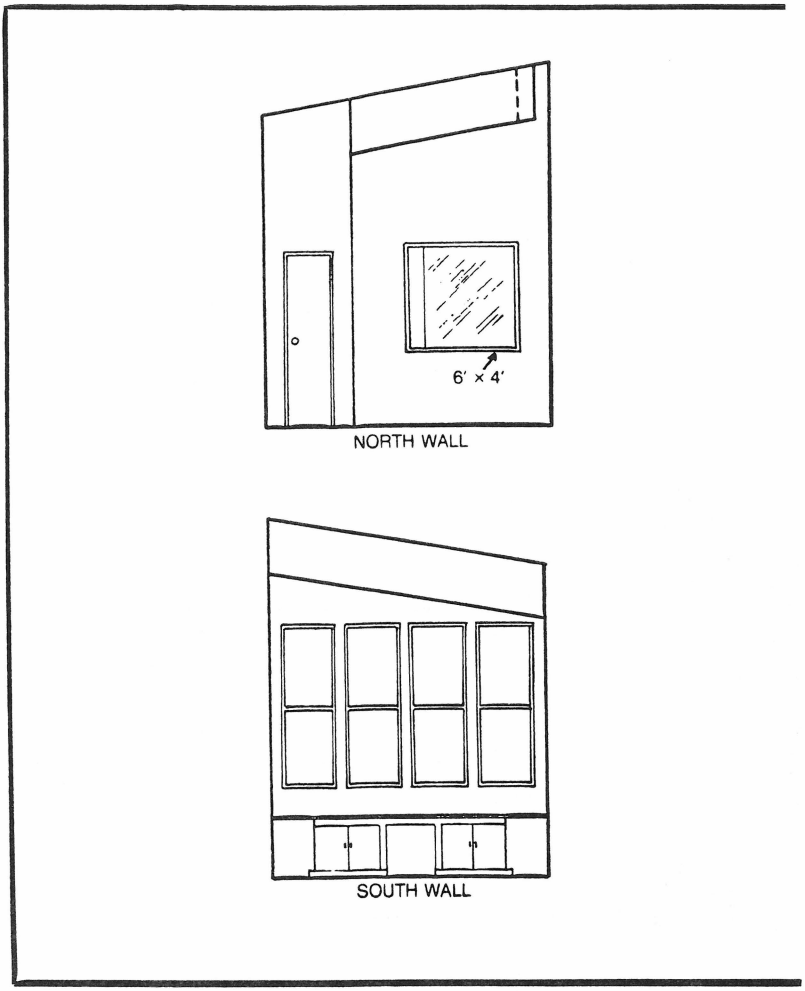
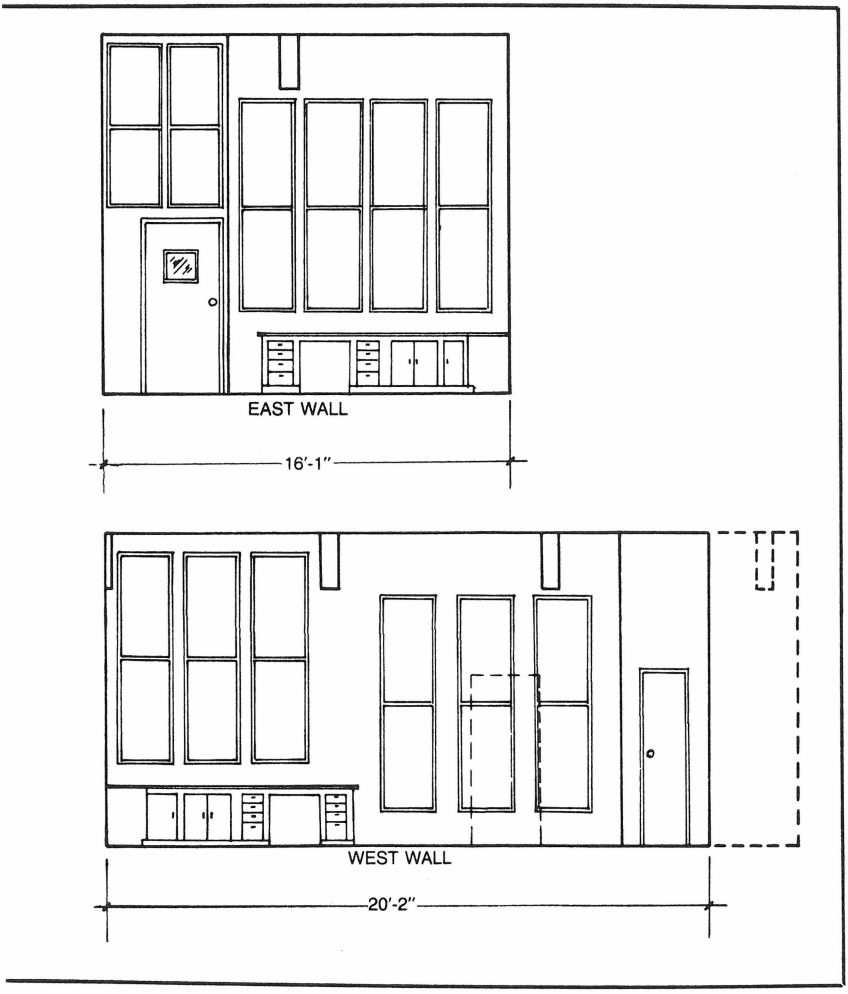


Fig. 4-9. The four wall elevations of the control room showing placement of wideband wall modules.

how this is done. If 703 of 4 inch thickness (instead of two 2 inch layers) is employed, the glass fiber-board is rigid enough to allow straightforward cementing to the ceiling. This method would not provide for the cosmetic grille cloth cover nor protection from small glass fibers falling, but acoustically it would be excellent. It may be desirable to stretch zig-zag wires between the edges of the frame of Fig. 4-8 under the cloth cover to hold the 703 in place and to avoid sagging of the cloth cover.



Wall Treatment

The 703 glass fiber is applied to control room walls in the same modular form as shown in Fig. 3-4. In the present case both 8 foot and 6 foot modules are used, both of similar construction. The 8 foot module really needs a divider in the middle for strength and to help the unit keep its shape. Unlike the 6 foot module of Fig. 3-4, a similar central divider is suggested in this case for a more uniform appearance. The wall modules are positioned as shown in Fig. 4-9.

Reverberation Time

With only 4 inches of 703 entering into our calculations for the control room, only a uniform reverberation time between 125 Hz and 4 kHz can be expected. In Fig. 4-7 this uniform reverberation time for the control room is shown by the broken line. It is somewhat lower than that of the studio it serves, which is as it should be.

AIR CONDITIONING

Figure 4-2 shows a possible location for the air conditioning equipment behind the entry door. A suspended ceiling in the entry hall would hide the ducts in this room. Metal ducts for both supply and exhaust lined with acoustically absorbent board are suggested. The paths of the supply ducts are shown by broken lines in Fig. 4-2 as an example. This supply duct for the studio follows the path b-c-d-e. The supply duct to the control room follows the path b-a. These duct routings would accomplish the following:

- Give one 90 degree bend at b between the control room grille and the A/C unit plus about 20 feet of lined duct length.
- Give two 90 degree bends at c and d between the studio and the A/C unit plus about 20 feet of lined duct length.
- Give 90 degree bends at b, c and d between the control room and studio plus about 20 feet of lined ducting.

This ducting plan should reduce A/C machinery and fan noise to an acceptable level and minimize the *speaking tube* effect between the control room and studio. The air velocity at the grilles should be kept below 500 feet per minute, a limit easily met. The exhaust duct routing should follow a similar plan to that of the supply ducts.

OBSERVATION WINDOW

The construction of this most important part of the studio complex must be carried out carefully, following the general plan of Fig. 2-11 except that with 10 inch thick brick walls, the frame need not be divided as with the staggered stud wall. The

frame should preferably be made of sturdy 2 inch thick lumber and mounted as the brick wall is being layed. The frame should be supported in the center by bracing during bricklaying so that the weight of bricks and mortar does not distort the window frame. Beads of acoustical sealant must be run between frame and mortar and plaster on both sides as hairline cracks commonly develop as the mortar and plaster dry.

Chapter 5
A Small Studio For Instruction and Campus Radio

Features: Window plugs, reversible wall modules, large poly diffuser/absorber, discrepancies between published coefficients and experience.

Many institutions of higher education have communication departments and most of these departments teach courses in electronic media (radio and television). Students in radio broadcasting need hands-on experience and this requires a small recording facility to serve as a practical laboratory. It is common for such students to produce programs to be broadcast over the campus system. The studio and control room which are the subject of this chapter are for precisely this purpose and continue to serve effectively in training students.

STUDIO PLAN

A classroom was made available for space for the studio and control room. Dimensions of 18 feet-10 inches × 21 feet-8 inches with a 10 foot-3 inch ceiling height are not what one would call munificent, but it represents a volume of almost 4200 cubic feet, which is fairly generous. The ceiling height of 10 feet-3 inches gives relief from 8 foot heights often encountered in budget renovation jobs. The floor plan of Fig. 5-1 was settled upon after a bit of horse trading. Many students were to be accommodated in the studio at one time as observers and

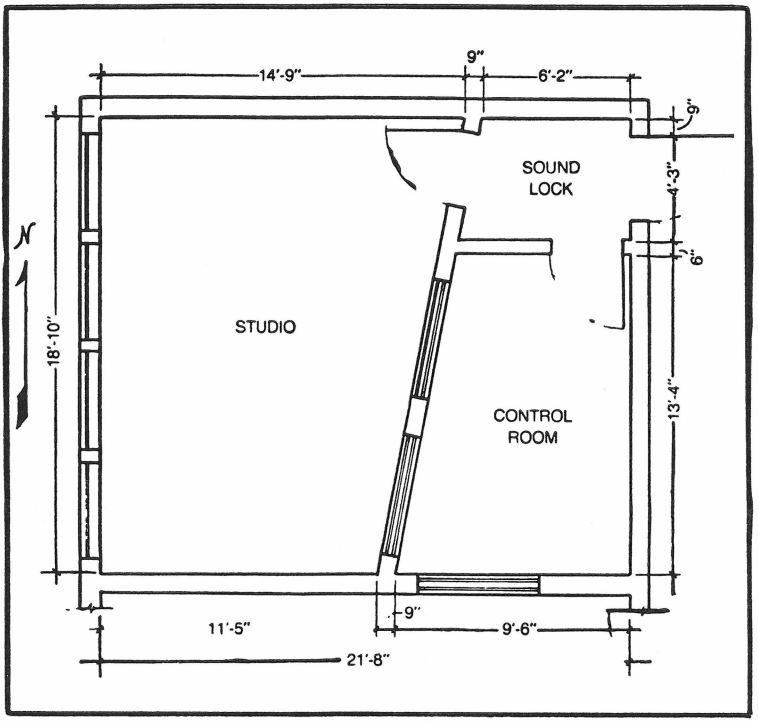


Fig. 5-1. Floor plan of a studio suite designed for student instruction in radio broadcasting in a college communication department. A former classroom was converted for this purpose.

performers, fewer in the control room. A studio volume of 2525 cubic feet, a control room volume of 1138 cubic feet and a sound lock were carved out of the classroom. This means that the control room volume was below the recommended minimum of 1500 cubic feet. This sacrifice made it possible to have a larger studio.

The angled wall separating the control room and the studio reduces the chances for flutter echo in both rooms, tends toward spreading out of model resonances and gracefully provides for reduction of the volume of the sound lock.

As for penetration of outside noise, concrete walls, ceiling and floor were comforting, but almost the entire west wall was taken up by four windows overlooking a very busy thoroughfare with many trucks growling up a steep hill. These windows were plugged by four thicknesses of ¾ inch chipboard (particle board) as shown in Fig. 5-2. This ¾ inch

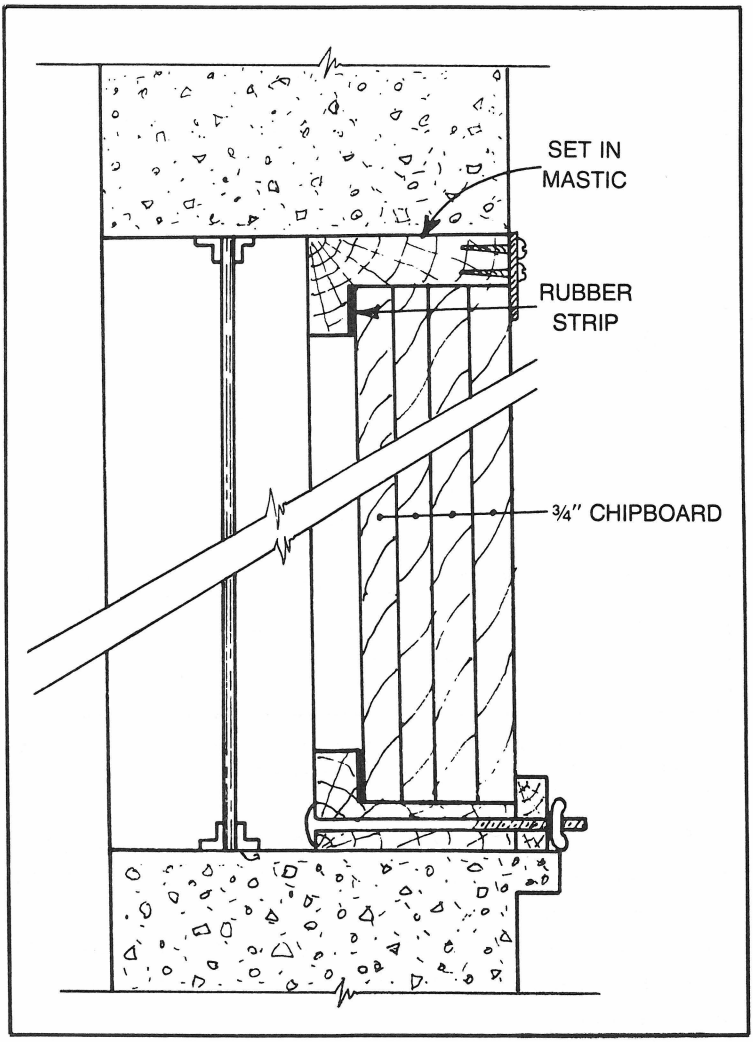


Fig. 5-2. Non-destructive and inexpensive window plug designed to protect the studio from exterior noise.

chipboard has a surface density of about 3 pounds per square foot. Four thicknesses bring the surface density to about 12 pounds per square foot. Considering only the mass and neglecting for the moment any resonance effort, such a well-sealed window plug should give a transmission loss of about 38 dB at 500 Hz, less for lower and more for higher frequencies. The frame holding the chipboard panels was sealed tightly to

the concrete window opening. The four chipboard panels were then sealed by a soft rubber strip as the panels were pressed into place. The optional carriage bolt arrangement makes possible the nondestructive removal of the panels if necessary.

STUDIO CEILING TREATMENT

Common suspended ceilings are rarely seen in studios. Before the end of this chapter is reached, some of the reasons for this state of affairs may be apparent. In the present case, such a ceiling was selected because it was attractive, cheap and promised some easily obtained low frequency absorption. Because of eye appeal, Johns-Manville Acousti-Shell Textured Vault 3-dimensional 24 inch × 24 inch ceiling panels were selected. Laying out the suspension grid on paper for

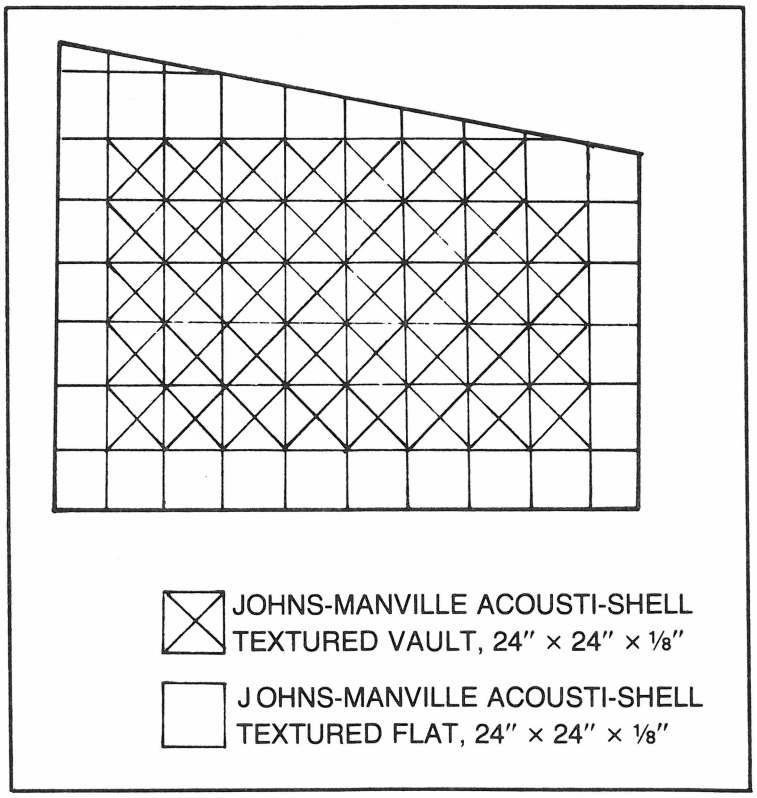


Fig. 5-3. Layout plan for suspended ceiling in studio.

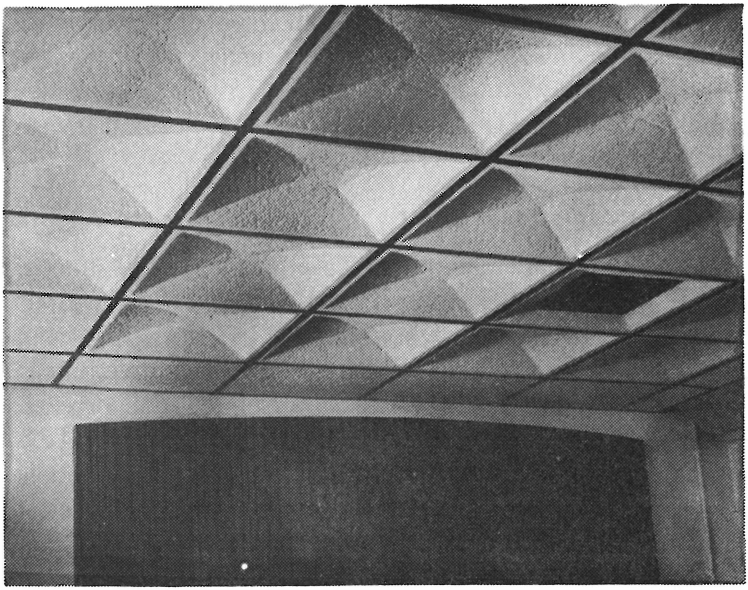


Fig. 5-4. Appearance of completed suspended ceiling in studio. To accent the 3-dimensional effect of the ceiling the room was illuminated by indirect light from fluorescent tubes over the observation windows.

such an odd shape emphasized the need for flat panels around the edges as shown in Fig. 5-3. The coordinated Acousti-Shell Textured Flats logically fill this role. A photograph of this attractive ceiling is shown in Fig. 5-4.

SEMICYLINDRICAL UNIT

For the south wall a large diffuser/absorber of semi-cylindrical shape was selected. The construction of this unit is detailed in Fig. 5-5. The skin is of ¼ inch plywood over which a very thin veneer was cemented for appearance. The frame is of 2 inch × 2 inch lumber and the space behind the skin is divided into nine sections by dividers of 1 inch lumber and curved bulkheads of 2 inch lumber over which the skin is stretched. This also gives the cylindrical segment its shape.

Bulkheads and dividers are sealed where they meet the plastered wall so that each of the nine segments is essentially air tight. A self-adhering foam rubber strip was applied to the edges of the 2 inch thick shaped bulkheads before the plywood skin was mounted. This made for a tight seal and made the

structure rattle-free. The photographs of Figs. 5-6 and 5-7 show the internal structure and the 2 inch insulation placed on the wall in each section. Figure 5-8 illustrates the finished appearance of this outsized cylindrical segment.

REVERSIBLE WALL PANELS

The west wall required some absorbing and diffusing elements to go over the plugged windows. Reversible panels of nominal 4 foot × 6 foot size (Fig. 5-9) were selected. The inside dimensions of the frame were adjusted to accept 24 Johns-Manville ¾ inch Temper-Tone acoustical tiles of 12

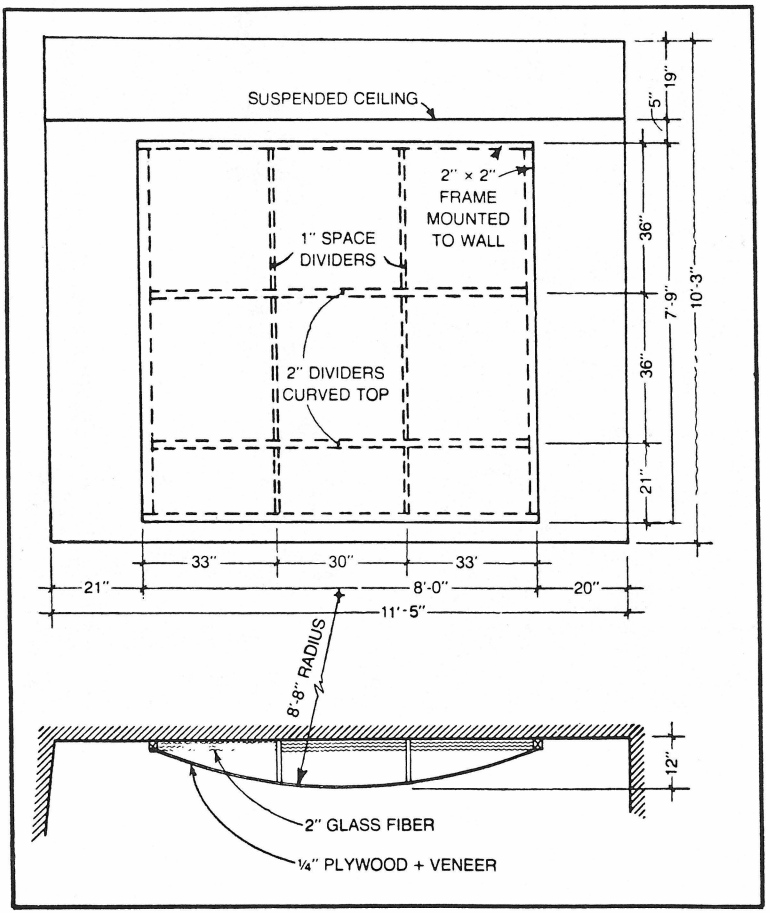


Fig. 5-5. Constructional details of a large semicylindrical diffuser/absorber mounted on the south wall of the studio.

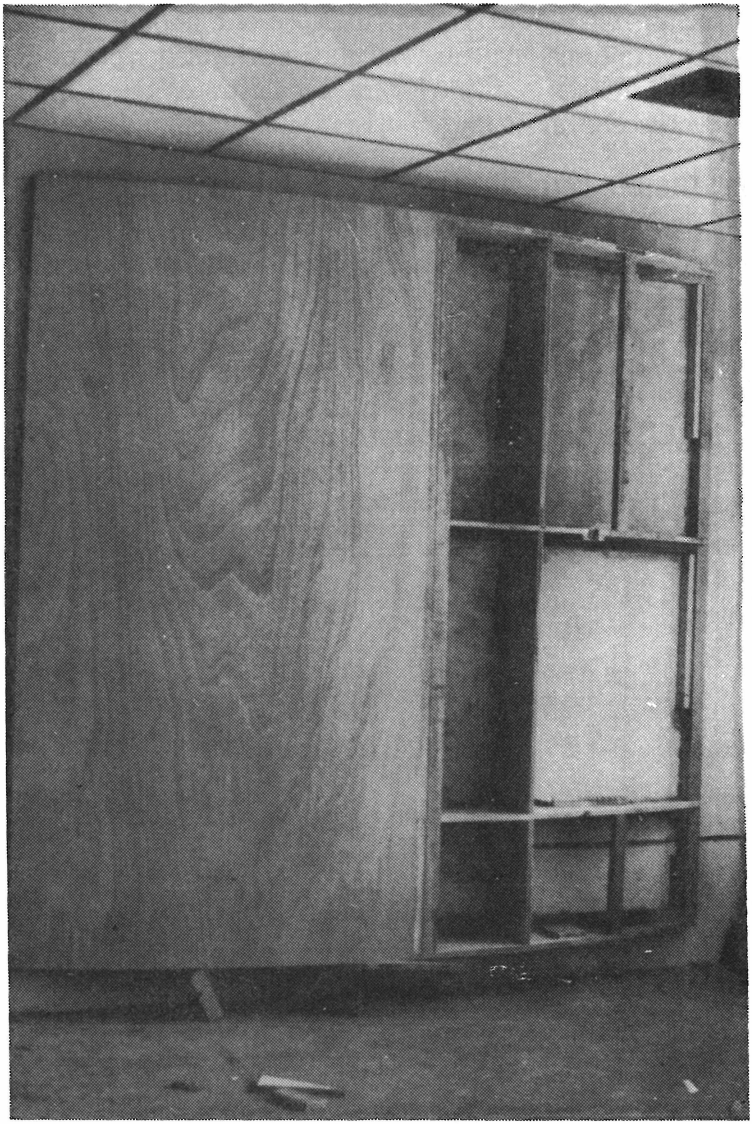


Fig. 5-6. View showing internal structure of curved bulkheads and dividers of semicylindrical unit on south wall.

inch × 12 inch size without cutting. These comprise the acoustically *soft* or absorbent side. The *hard*, reflective side is made of ¾ inch plywood. The center of this reflecting surface is higher than the edges, avoiding flat reflections back to nearby microphones.

The size of this reflective panel determines, of course, that such a diffusing effect is primarily at the higher audible frequencies. Although these are called *reversible*, it was recognized in advance that once hung they would probably never be changed. However, the dual-sided approach kept open some options during the testing phase. Either simple angle brackets may be used in mounting such wall elements or, if reversals are probable, two pins in the bottom of each unit can fit into holes in metal brackets affixed to the wall to carry the weight. A simple latch arrangement can also be installed to hold the top of the unit against the wall.

Figure 5-10 shows all four studio wall elevations and the treatment for each. The north wall simply has 36 Johns-Manville Temper Tone 360 acoustical tiles of ¾ inch thickness mounted in two patches. The south wall is dominated by the 8 foot semicylindrical element previously described. The east wall is almost completely taken up by two observation windows and the door. The west wall has three of the reversible wall elements of Fig. 5-9. The location of the plugged windows is indicated by broken lines.

The suspended ceiling line is indicated on each wall elevation 19 inches below the structural ceiling. This distance

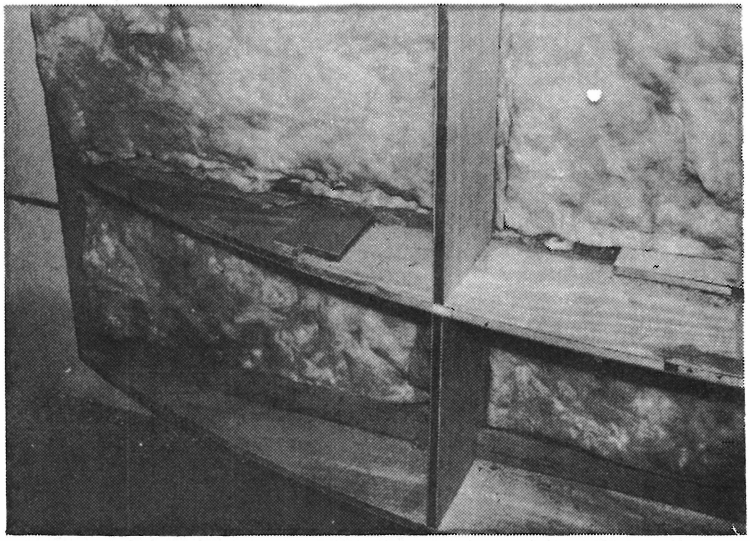


Fig. 5-7. A self-adhering strip of foam rubber on the edges of curved bulkheads and dividers assures tight sealing of compartments and freedom from rattles.

Fig. 5-8. View of completed diffuser/absorber on the south wall of studio. A thin veneer glued to curved plywood surface improves appearance with no serious degradation of function.

allows the accommodation of air conditioning ducting. This means that some uncertainty is introduced in the absorption coefficients which are given for a standard Mounting #7 distance of 16 inches.

STUDIO CALCULATIONS

For those who wish to follow through on the calculations of studio reverberation time, Table 5-1 is included. It is really

Table 5-1. Studio Calculation.

SIZE ..... 18' - 10" × 14'9" × 11 5" (one wall splayed)
CEILING ..... Johns-Manville Acousti-Shell TV&TF 24" × 24" × ⅝". suspended 19"
SURFACE AREA ..... 1151 sq. ft.
FLOOR ..... Plastered concrete, treated as below
WALLS ..... Vinyl tile
VOLUME .....

Material	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
J—M Acousti-Shell Textured Vault	156	0 64	99 8	0.66	103 0	0 67	104 5	0 75	117 0	0 72	112 3	0 70	109 2
J—M Acousti-Shell Textured Flat	90	0 70	63 0	0 69	62 1	0 66	59 4	0 80	72 0	0 84	75 6	0.83	74 7
Floor, vinyl tile	246	0.02	4 9	0 03	7 4	0 03	7 4	0 03	7 4	0 03	7 4	0 02	4 9
Glass	30	0 05	1 5	0 03	0 9	0 02	0 6	0 02	0 6	0 03	0 9	0 02	0 6
Plaster	458	0 02	9 2	0.03	13 7	0 04	18 3	0.05	22 9	0 04	18 3	0 03	13 7
Door	20	0 24	4 8	0 19	3 8	0 14	2 8	0 08	1 6	0 13	2 6	0 10	2 0
Cylindrical Element, South wall	62	0 50	31.0	0 35	21 7	0 22	13 6	0 14	8 7	0 11	6 8	0 10	6.2
J—M Temper Tone tile, North wall	36	0.09	3.2	0.25	9.0	0 70	25 2	0 85	30 6	0 83	29 9	89	
			217 4		221 6		231 8		260 8		253.8		243 3
West wall panels, hard	72	0 28	20 2	0 19	13 7	0 14	10 1	0 11	7 9	0 08	5 8	0 05	3 6
Total sabins, hard, Sa			237 6		235.3		241 9		268 7		259 6		246.9
Ave. Absorp. coeff., a		0 206		0.204		0.210		0 233		0 226		0 215	
Reverb. Time, sec.		0 47		0 47		0 46		0 41		0 42		0 44	
West wall panels, soft	72	0.2	14 4	0 5	36 0	1 0	72 0	1 0	72 0	1 0	72 0	1 0	72 0
Total sabins, soft, Sa			231.8		257.6		303 8		332 2		325 8		315 0
Ave. Absorp. coeff., a		0 201		0.224		0 264		0 289		0 283		0 274	
Reverb Time, sec.		0 48		0 42		0 35		0 32		0 32		0 34	

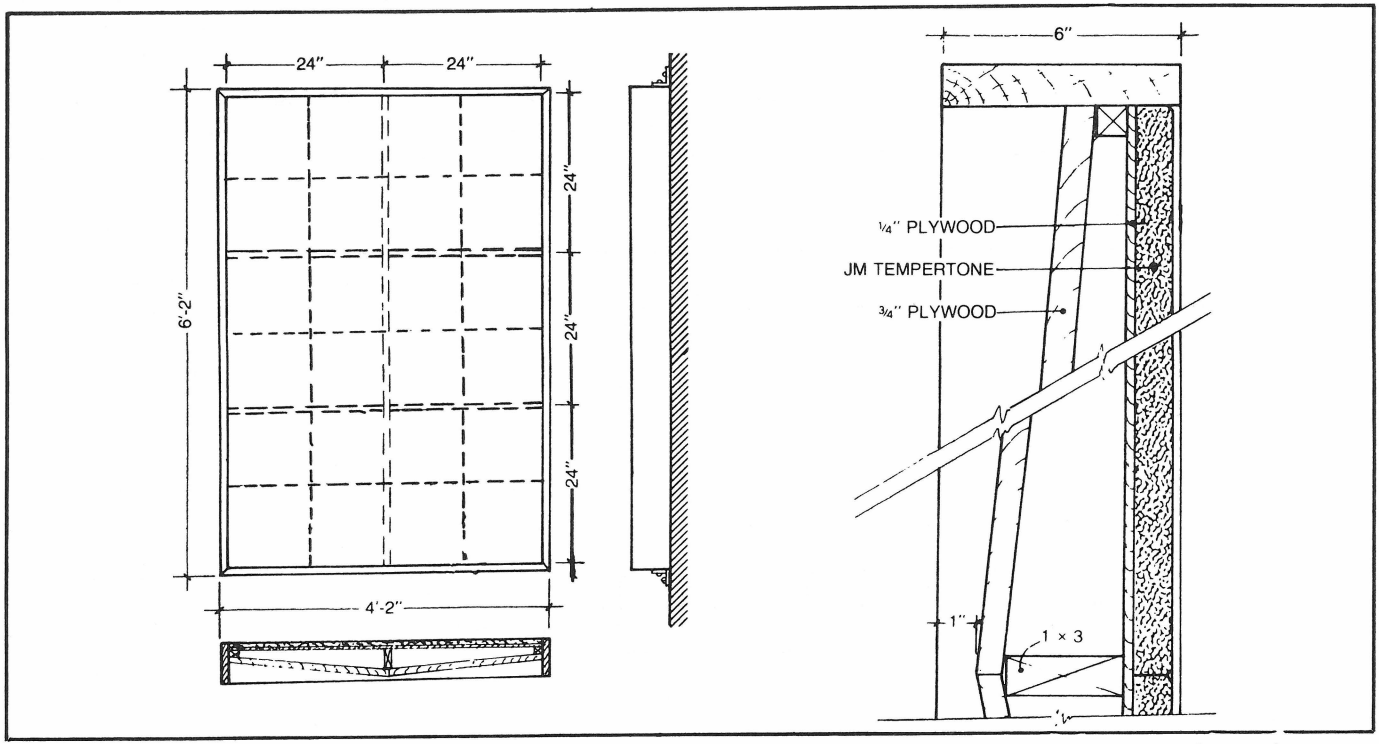


Fig. 5-9. Construction details of reversible units on west wall over the plugged windows. The reversible feature is intended more for allowing some final adjustments in room acoustics during measurements than for changing between program types.

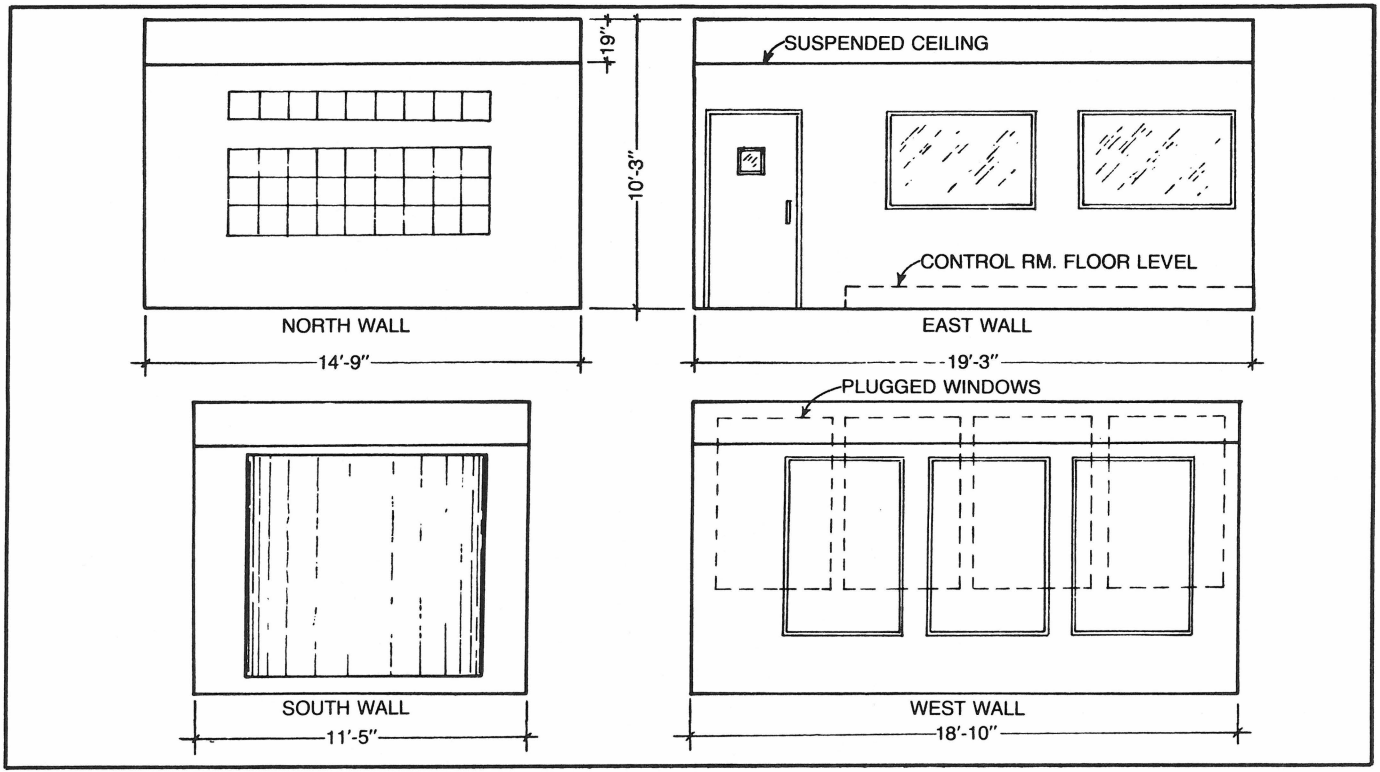


Fig. 5-10. Placement plan for acoustical elements on four walls of studio.

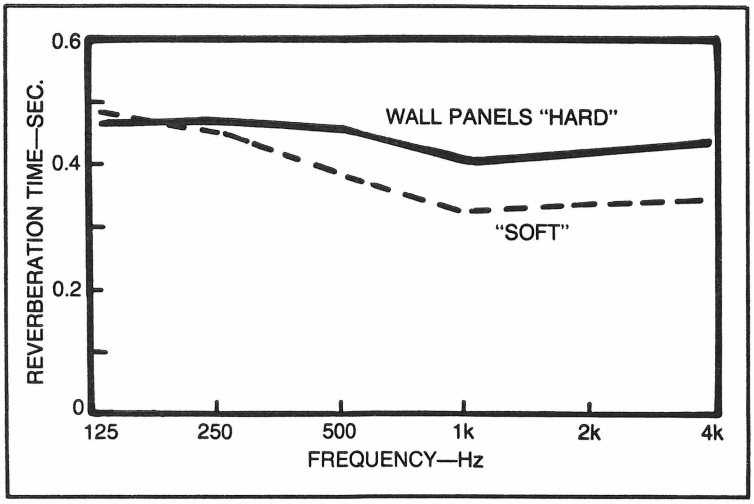


Fig. 5-11. Effect on calculated studio reverberation time of reversing the three panels on west wall.

"gilding the lily" to separate out absorption of door and observation window glass in view of the uncertainties in all coefficients of absorption, but no harm is done by including them as long as limitations of our overall precision is kept in mind. Computations are included for the three units on the west wall with both the reflective (hard) and absorptive (soft) sides facing the room. Calculated reverberation times for these two conditions, taken from Table 5-1, are shown graphically in Fig. 5-11. By turning the units from soft to hard, an increase in reverberation time of about 30 percent is obtained for frequencies above 500 Hz. Looking at things the other way around, by changing from hard to soft a reduction in reverberation time of about 23 percent results for the higher frequencies.

CONTROL ROOM

The control room, as mentioned previously, is substandard in volume, a compromise designed to accommodate a greater number of students in the studio. Figure 5-12 illustrates the very practical equipment arrangement utilized. Room for two standard racks for 19 inch panels of ancillary equipment was allowed at the north wall. Along the south and west walls were placed work surfaces with built-in drawers

and storage cabinets below. The window in the south wall looks into the television studio. Although the television studio has its own control room, this window, along with interconnecting tie lines, makes it possible to use both studios for special productions. Normally this south window is covered by drawn drapes.

The floor of the control room was raised about 12 inches and a 4 inch × 4 inch trough runs around the east, south and

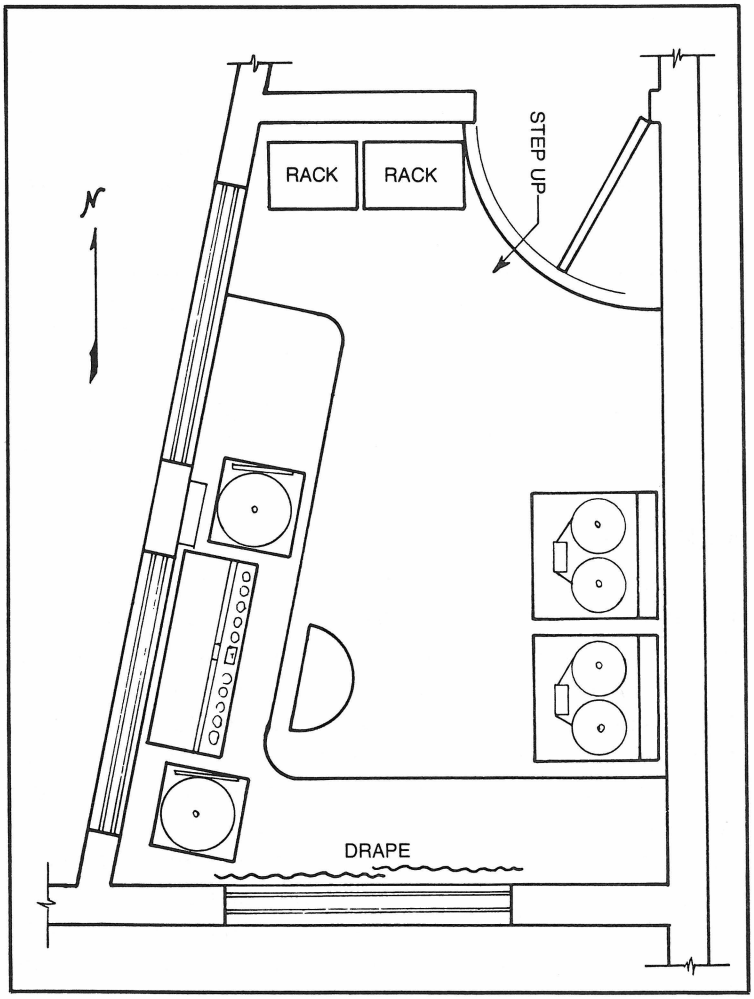


Fig. 5-12. Control room equipment layout. Control room space is considerably less than ideal in order that many students can be accommodated in the studio at one time.

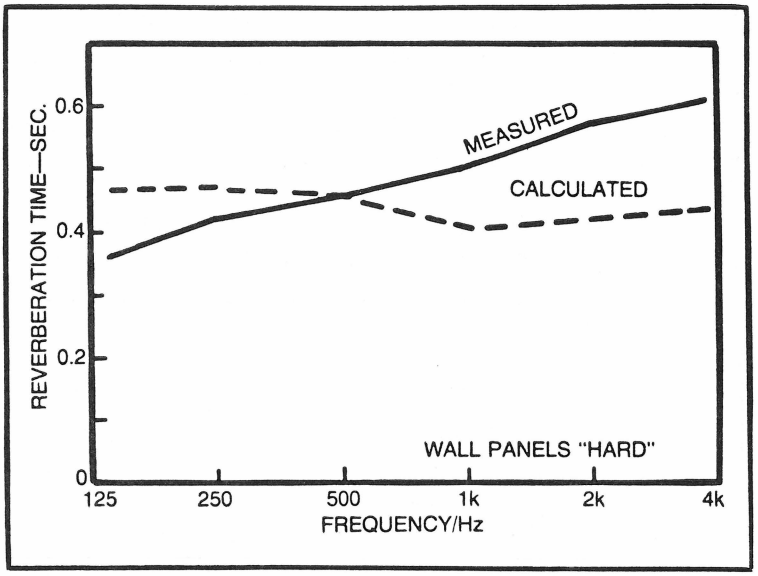


Fig. 5-13. Comparison of measured and estimated reverberation time of studio in exercise to illustrate basic problems involving sound absorption coefficients in computations.

west walls for interconnecting cables. In spots not covered by cabinets, access to the trough is by hinged lids flush with the floor.

MEASUREMENTS

Listening tests in the studio revealed that with the hard surfaces of the three west wall panels exposed, the sound was somewhat too *bright* , that is , the high frequency components of music and speech were too prominent. For a studio of 2525 cubic feet the optimum reverberation time for music is about 0.5 second and for voice about 0.3 second. This studio, to be used for both, should have a compromise reverberation time somewhere between the two. Flipping the west wall units first one way for a music program and then the other for speech is just too much trouble; many programs involve both. The object, then, is to determine by actual measurements which way these panels give the best compromise effect and then leave them that way.

Reverberation measurements were performed using interrupted octave bands of pink noise to evaluate the accuracy

of the computations and to determine the proper exposure of the west wall panels. In Fig. 5-13 the measured and calculated values of reverberation time are compared for the west wall panels hard condition. At 500 Hz the agreement is perfect but calculated values are too high at low frequencies and too low at high frequencies. This means that there is greater absorption at low frequencies and less absorption at high frequencies than the coefficients of Table 5-1 indicate. These measured results surely explain why the sound was too bright with hard panels!

With the west wall panels exposing the Johns-Manville Temper Tone acoustical tile (the soft condition, see Fig. 5-9), the calculated values are again too high at low frequencies and too low at high frequencies as shown in Fig. 5-14. In the mid-frequency region there is excellent agreement at 500 Hz and 1 kHz.

Figure 5-15 compares measured reverberation time between the hard and soft conditions of the west wall panels. The measured comparison of Fig. 5-15 shows the same type of separation for the higher frequencies as the calculated comparison of Fig. 5-11. Otherwise the agreement is not too good.

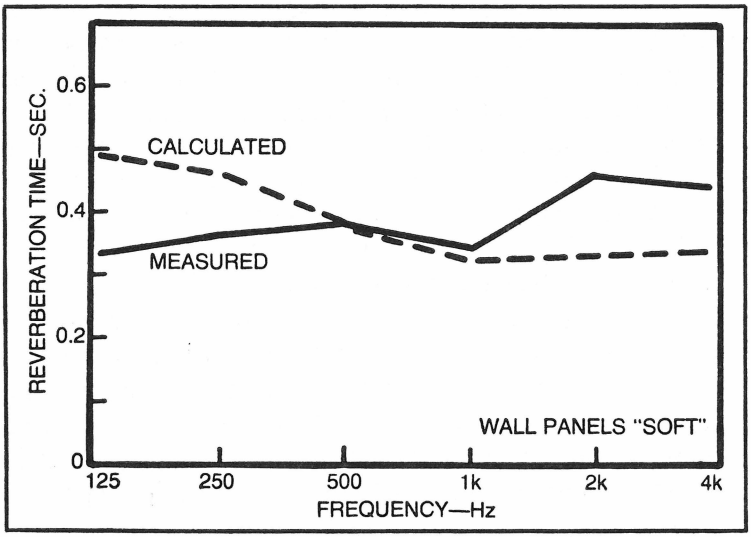


Fig. 5-14. Comparison of measured and calculated reverberation time of studio with west wall panels soft side out. Calculated values of reverberation time are the same as those in Fig. 5-11.

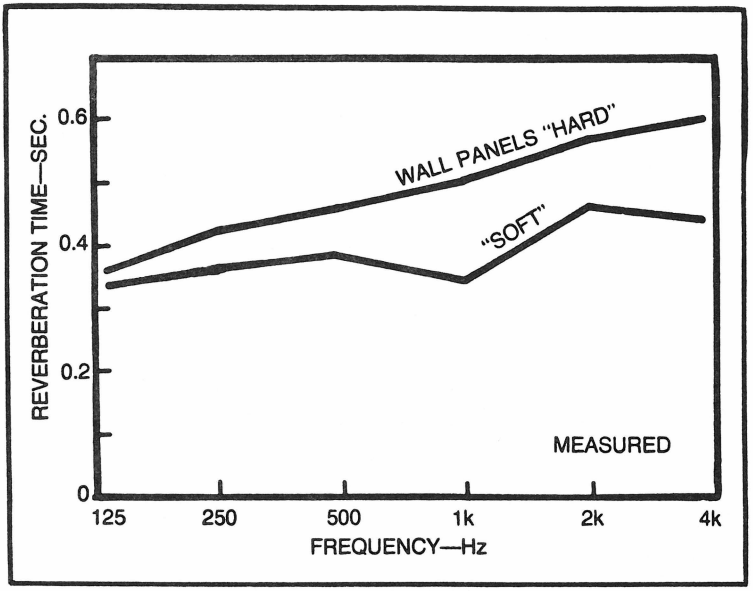


Fig. 5-15. Comparison of measured studio reverberation time with reversal of west wall panels. The soft graph is the same as in Fig. 5-14.

Glancing down the various materials of Table 5-1 and the absorption coefficients used for each, one asks the question, "Which ones are in error?" One relatively unfamiliar component was the suspended ceiling. In Table 5-1 good absorption is attributed to it both at low and high frequencies. Is this substantial portion of the total absorption actually realized in practice across the band? Measurements were made both with the suspended Acousti-Shell panels in place and with them removed from the room with the results shown in Fig. 5-16. AHA! There is the expected absorption in the low frequencies, but essentially none at 2 and 4 kHz!

Is the measured low frequency absorption really the expected amount? A simple computation can settle that question. The measured reverberation time at 125 Hz with the suspended ceiling in place was 0.33 second. With the ceiling removed, and no other change in the room, it was 0.65 second. By feeding these values back into Eyring's equation, corresponding values of 320 and 175 sabins of absorption for the two conditions are obtained. The difference of 145 sabins can only be attributed to the suspended ceiling. In our calcula-

tions of Table 5-1, 99.8 + 63.0 = 162.8 sabins were assigned to the ceiling. This means the suspended ceiling yields a modest 11 percent less absorption at 125 Hz than the manufacturer's coefficients would indicate.

The AcoustiShell ceiling is actually 19 inches from the structural ceiling rather than the standard 16 inches for which the coefficients were obtained. This may account for the difference. Yet in Figs. 5-13 and 5-14 the calculated low frequency reverberation times are too high, not too low. Where does all this absorption at 125 Hz come from? The semicylindrical element on the south wall is suspect. The assumed absorption coefficient of 0.5 may be too low. If this unit were resonant at 125 Hz, the highest possible coefficient it could have would be 1.0. If this were the case, the calculated reverberation time for the soft west wall panel condition would be brought down to about 0.42 second. This is in the right direction but only about half way to the measured value.

Where else can we look for some unexpected low frequency absorption? The graphs of Figs. 5-13, 5-14 and 5-16

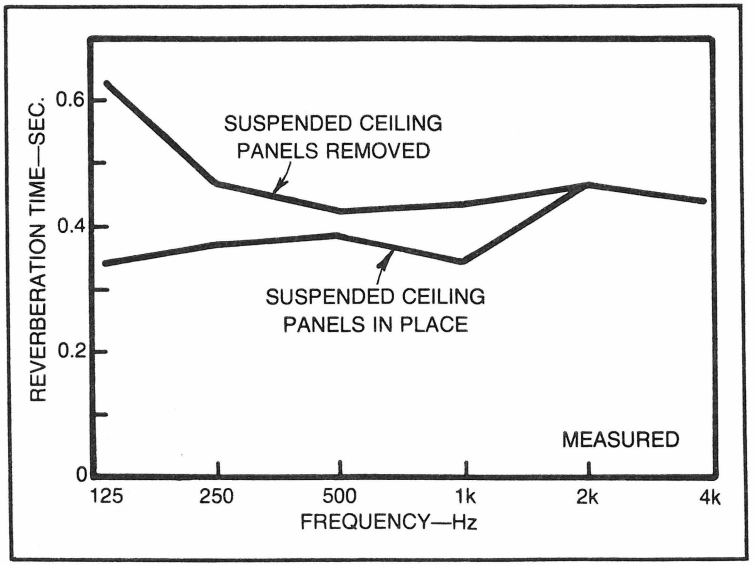


Fig. 5-16. Measurements of studio reverberation time reveal that for some unknown reason the high frequency absorption of the suspended ceiling is not realized in this installation. This emphasizes the need for confirming measurements of actual reverberation time before a studio job can be considered complete.

are for the west wall panels in the soft position with the Johns-Manville Temper Tone acoustical tile facing the room. The coefficients used in Table 5-1 for the Temper Tone tile on the north wall are those provided by the manufacturer for the tile cemented to a solid wall. In Fig. 5-9 there is a substantial air space behind the tile on the panels. This would surely enhance both low and high frequency absorption of the west wall units with the Temper Tone tile exposed.

The coefficients used in Table 5-1 for the west wall units, soft side out, are wild estimates designed to allow for the effect of the air space backing as well as the diaphragm effect of the ¼ inch plywood backing. The absorption coefficient assumed for these tiles, soft side out, at 125 Hz, is 0.2. If it could be stretched to the limit of 1.0, the remainder of the lost absorption at low frequencies would be accounted for. Perhaps 100 percent absorption at 125 Hz is a rather optimistic assumption for both the semicylindrical unit on the south wall and the three panels on the west wall. But at least something close to 100 percent for these and some slack in other 125 Hz coefficients helps to correlate measurements and calculations. It also educates us on the flimsy nature of some of these coefficients. So much for disparity between low frequency measurements and calculations.

In both Figs. 5-13 and 5-14 the measurements reveal that less absorption is realized in the high frequencies than the coefficients of Table 5-1 give. The measurements of Fig. 5-16, with and without the suspended ceiling, reveal that for some reason or other the Acousti-Shell elements seem to give no appreciable absorption at 2 kHz and 4 kHz. In Table 5-1, 109.2 + 74.7 = 183.9 sabins are attributed to the suspended ceiling at 4 kHz. If these sabins are eliminated, only 131 sabins remain for the soft wall panel condition which gives a reverberation time of 0.89 second, far higher than the 0.44 second measured. Total absorption of 249 sabins is required to account for the 0.44 second measured reverberation time. It would appear that something like 66 sabins are being obtained either from the ceiling or some of the other sound absorbing elements listed in Table 5-1.

This has been a tedious excursion into the field of practical absorption coefficients. As James Moir, prominent British

acoustician, has said, "Anything that is obvious in acoustics is nearly always wrong."[11] Perhaps the tedium is worthwhile if we learn only one thing, that absorption coefficients are the insecure basis of our reverberation time calculations and that our computed results are no more dependable than the coefficients used.

Absorption coefficients supplied by manufacturers for their proprietary materials may or may not be realized in practice, depending on how closely the practical mounting and surroundings approximate those of the measuring conditions.

For the non-proprietary acoustical elements, such as the semicylindrical south wall unit, finding even approximate coefficients is a great problem and we are even more vulnerable to error. Computations, carefully done, serve only as a rough guide. Measurements and subsequent *tuning adjustments* are essential to accurate acoustical treatment of studios, control rooms and other critical listening spaces.

Chapter 6
Small Ad Agency Studio
For AVs and Radio Jingles

Feature: Use of midband absorbers

An advertising agency had a small, makeshift recording facility which was both cramped and poorly layed out. Expansion of agency business required moving up one floor in their large commercial building to provide the space needed. In the process the recording facilities were also to be enlarged and restructured. As is so often the case, those doing the actual recording work found themselves on the wrong end of the totem pole with their space shrinking daily as front office ideas grew during the planning stage. A space at one end of the floor between two concrete walls was eventually designated for studio use. The walls effectively blocked expansion north and south.

The primary use of this facility is in the production of radio advertising announcements. A secondary growing activity is production of audiovisuals, principally slide sets and filmstrips. Two rooms were envisioned, one to be devoted principally to the recording and audiovisual functions, the other to be a combination control room for recording and a general work room in which mixing, editing and dubbing would also be done. Several people, each working on a different project or at least different aspects of the same project, were bound to get in each other's way from time to time but the "gigantic step forward for mankind" which the new facility offered over the old one made such conflicts seem trivial.

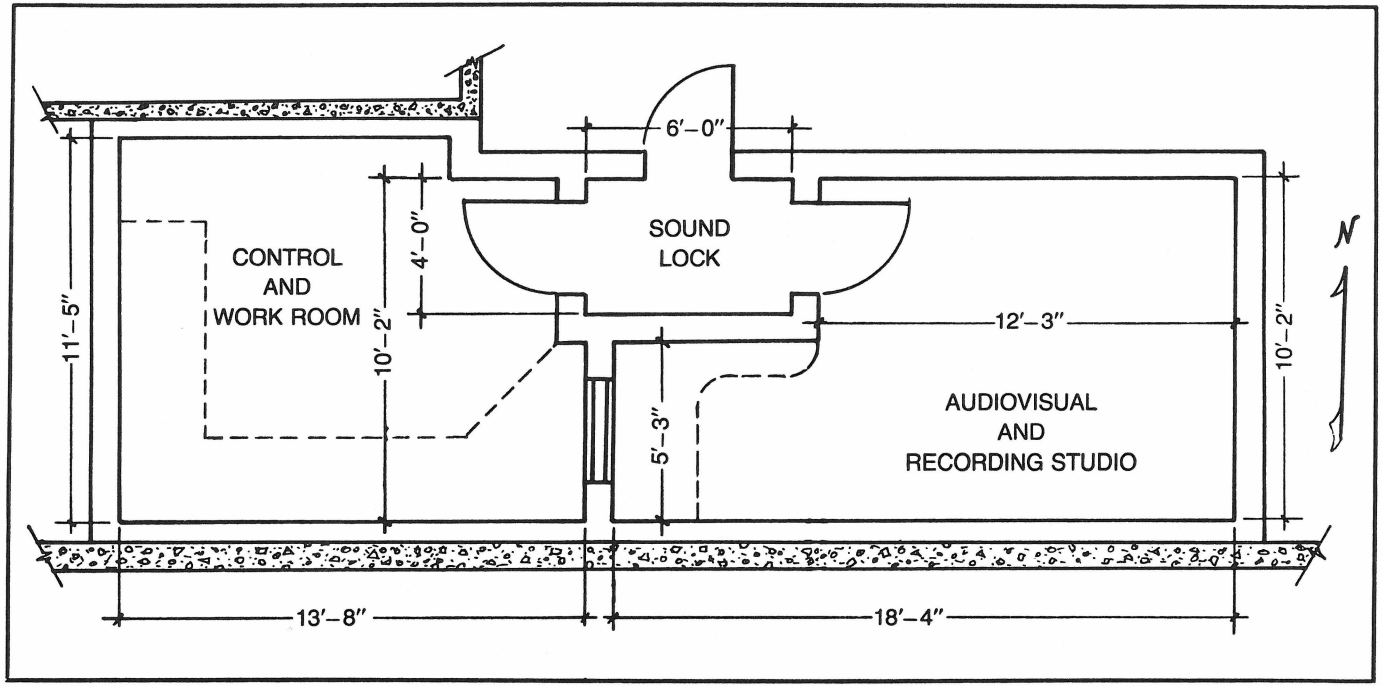


Fig. 6-1. Floor plan of work room and recording studio wedged in between two existing concrete walls. Due to space limitation it was necessary to take the sound lock space from the studio.

FLOOR PLAN

The floor plan emerging from the smoke and fire of space allocation, incorporating the best functional ideas of production personnel and acoustical consultant, is shown in Fig. 6-1. It incorporates some basic problems, such as volumes below the 1500 cubic foot minimum (but not much below). Because sound lock space had to be taken from the studio, a cavity is created in the recording studio near the observation window. The temptation to sit in this cozy indentation at the built-in table near the window is great, especially for those nurtured on the radio tradition of the announce booth. The better position for the narrator during recording is back in the main part of the room and not in this indentation. The indentation would not have existed if sound lock space could have been allotted outside the studio area.

The control work room has a built-in work surface along the south and west sides of the room. This bench carries a mixing console as well as numerous advanced audiophile type magnetic recorders.

ROOM PROPORTIONS

As we saw in Chapter 1, axial mode distribution is something of a problem even when we are free to specify the three dimensions of a room. In this case, two of the three dimensions of both rooms were fixed by circumstances and tight constraints placed on the third. All that can be done in such circumstances is to study the distribution of fundamental resonance frequencies and harmonics of the space in an attempt to evaluate the threat of colorations on paper before construction is started.

Figure 6-2A is a plot of modal frequencies for the audiovisual/recording studio. The solid lines are associated with the basic 18 foot-4 inch length, 10 foot-2 inch width and 8 foot-11 inch ceiling height (the length of the lines of Fig. 6-2 holds no significance). The broken lines are associated with the 5 foot-3 inch alcove in the N-S mode and the 12 foot-3 inch step in the E-W mode.

Some of these secondary dimensions within the room (broken lines) occur in rather large gaps between major reso-

nances (solid lines), which is favorable, while others are almost coincident with major dimension modal frequencies, which can be unfavorable. The triple coincidence at about 277 Hz is probably no threat because few colorations are found to be problems above 200 Hz.[3] The three or four double pile-ups or near pile-ups below 200 Hz may or may not be troublesome. These will require the application of a keen ear for evaluation.

The solid lines of Fig. 6-2B represent the modal resonance picture for the control work room major dimensions of a 13 foot-8 inch length, 11 foot-5 inch width and 8 foot-11 inch ceiling height. The broken lines are associated with the 10 foot-2 inch N-S secondary step in the room width. With the exception of one at 167 Hz, all the secondary resonances land nicely between the major dimension resonances. In our keen ear analysis of this room, particular attention should be given to the possibility of colorations due to the double coincidences near 125 Hz and 166 Hz.

WALL CONSTRUCTION

It was immediately recognized that other diverse and noisy activities in the building could easily be carried to and

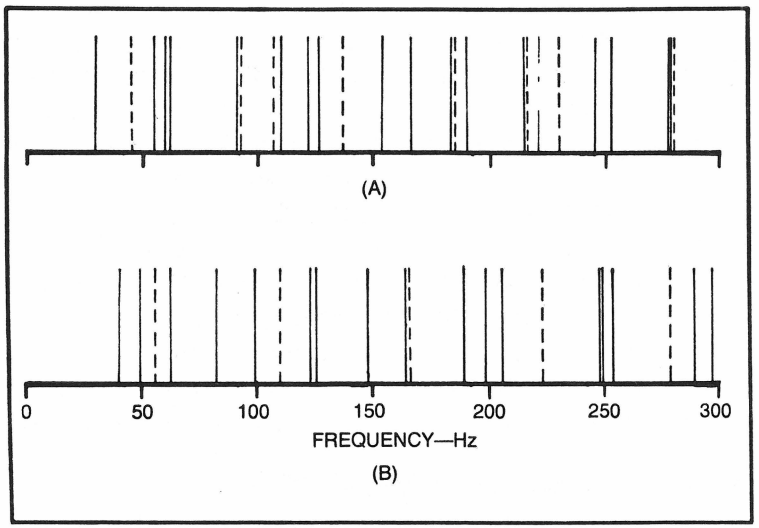


Fig. 6-2. Distribution of axial modal frequencies: (A) for the audiovisual recording studio and (B) for the control work room. The solid lines are associated with the basic dimensions of the rooms, the broken lines with secondary dimensions of alcove and step.

radiated in the sound sensitive spaces by the concrete structure of the building. For example, elevator equipment mounted securely to the structure sends impulses into the reinforced concrete walls and pillars and these can be radiated into the studios by concrete surfaces acting as diaphragms. Isolating against such noises took on a high priority. Floating concrete floors were ruled out by budget limitations, but something could be done about walls and ceilings.

Walls paralleling existing concrete surfaces are set back, creating a 3 inch air space which is filled with glass fiber insulation. Metal studs 2½ inches thick form the framework and a double layer of ⅝ inch gypsum board make up the mass of the wall surface facing the studio. Other walls, including the one in which the observation window is set, are constructed as double metal stud walls separated by 3 inches. The space is filled with glass fiber insulation. Double gypsum board on both faces yield an overall wall 10½ inches thick with a rating in the vicinity of STC-50. The ceiling is suspended from the structural ceiling with a vibration isolation hanger on each wire. A black iron angle frame holds the double ⅝ inch gypsum board ceiling. All gypsum board edges are staggered and all joints caulked with non-hardening acoustical sealant.

This plan provides a reasonable degree of isolation from building sounds on all surfaces but the floor. It was decided that if the floor did become a problem, a wooden floating floor could be added at a later time at minimum cost. Such structure borne sounds can be a serious problem. The author was visiting a fabulous new government broadcasting house in a certain foreign land. The architect had claimed 90 dB transmission loss as protection against nearby jet landing pattern noise by the studio-within-a-studio technique. Stepping into one of the beautifully treated and decorated studios, however, a distinct hammering noise from another part of the building was clearly heard to the embarrassment of the engineer-host.

AUDIOVISUAL RECORDING STUDIO TREATMENT

The acoustical treatment of the audiovisual recording studio involves four basic elements: the carpet, wideband wall units (2 feet × 4 feet), midband wall units (2 feet × 2 feet) and the low frequency ceiling units (4 feet × 5 feet). The

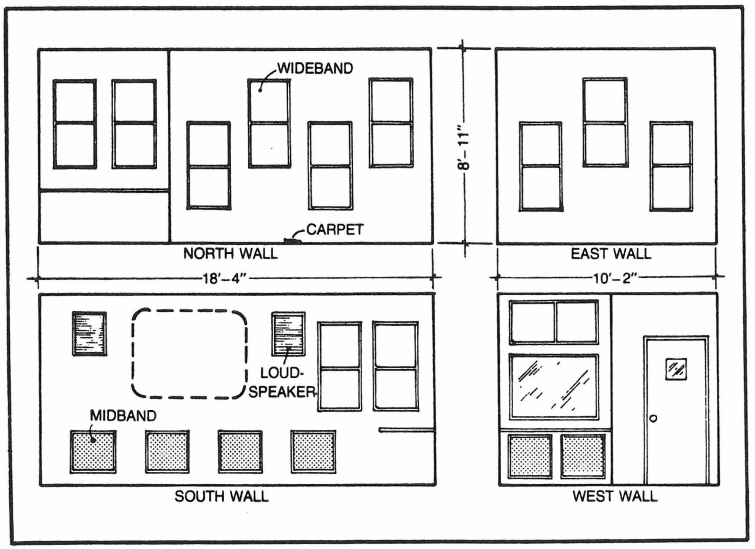


Fig. 6-3. Wall elevations of audiovisual recording studio showing placement of wideband and midband absorbers.

absorption of the gypsum board walls and ceiling has been neglected in the discussion to follow, but will be treated later in the chapter.

Figure 6-3 shows the placement of the wall units, Fig. 6-4A the placement of the ceiling units and Table 6-1 tabulates the computations for this room. Entering into Eyring's formula the room volume of 1390 cubic feet, the surface area of 818 square feet and the reverberation time goal of 0.3 second, an average absorption coefficient of a = 0.242 is obtained. From this the total absorption units to give us a reverberation time of 0.3 second is found to be Sa = (818) (0.242) = 198 sabins. The problem now becomes one of juggling the areas of the four types of absorbers to give us close to 0.3 second reverberation time across the band.

To obtain a uniform reverberation time throughout the audible spectrum requires a constant number of absorption units (sabins) with frequency. In Table 6-1 the total sabins at each frequency is fairly close to the calculated 198 required, varying from 195 to 211.3. To see more clearly how absorption of each type of material varies with frequency, the data of Table 6-1 is graphically presented in Fig. 6-5. The greatly unbalanced carpet absorption (Fig. 6-5A) is quite well com-

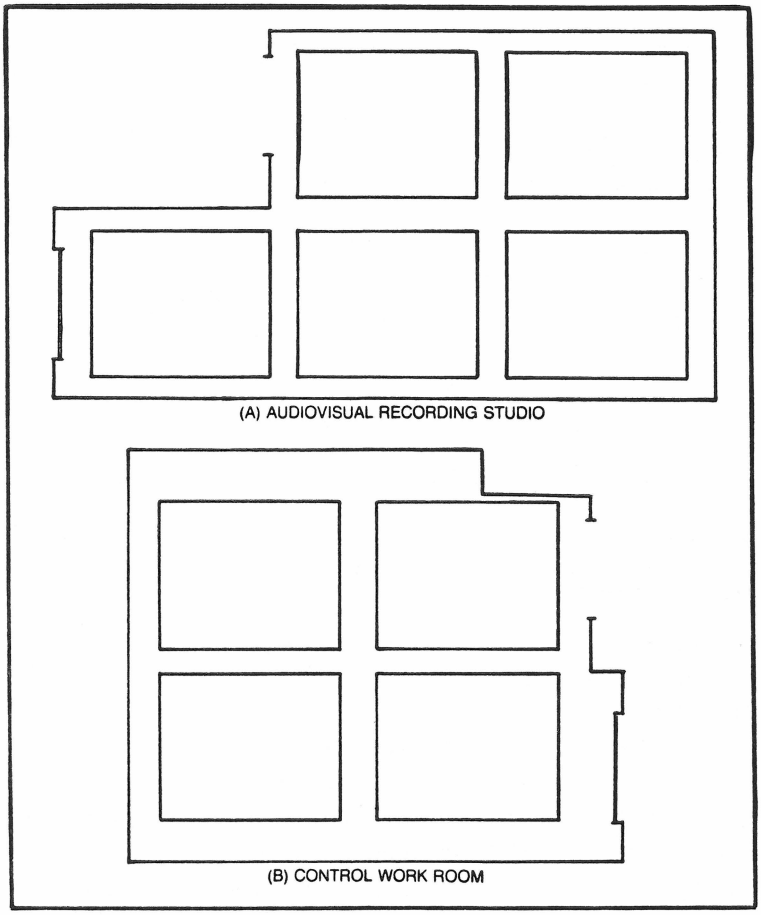


Fig. 6-4. Projected ceiling plans showing placement of the 4 foot × 5 foot low frequency units on the ceiling: (A) audiovisual recording studio and (B) control work room.

pensated by the equally, but opposite, imbalance of the low frequency ceiling units. However, there is a sag at midrange frequencies of the low frequency plus carpet curve (Fig. 6-5B) and the midrange units, tuned to the 500 Hz-1 kHz region, are designed to straighten out the carpet + LF + midrange curve (Fig. 6-5C). Once this is done, enough wideband absorber is introduced to raise the total to approximately the 198 sabin level (Fig. 6-5D). This gives close to 0.3 second reverberation time across the audible range shown in Fig. 6-6.

Table 6-1. Audiovisual Recording Studio Calculations.

SIZE .....10′–2″ × 18′–4″ × 8′–11″ ceiling ht.
FLOOR.....Carpet
CEILING .....5 Low Frequency Absorbers
WALLS .....12 Wideband, 6 Midband Absorbers
SURFACE AREA.....818 sq. ft.
VOLUME.....1390 cu. ft.

MATERIAL	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	157	0.05	7.9	0.15	23.6	0.30	47.1	0.40	62.8	0.50	78.5	0.60	94.2
Low Freq. Absorbers 5–4′×5′	100	1.0	100.0	0.68	68.0	0.39	39.0	0.17	17.0	0.13	13.0	0.10	10.0
Midband Absorbers 6–2′×2′	24	0.35	8.4	0.63	15.1	0.88	21.1	0.84	20.2	0.66	15.8	0.35	8.4
Wideband Absorbers 12–2′×4′	96	0.99	95.0	0.99	95.0	0.99	95.0	0.99	95.0	0.99	95.0	0.99	95.0
Total sabins, Sa			211.3		201.7		202.2		195.0		202.3		207.6
Ave. Absorp. Coeff, a			0.258		0.247		0.247		0.238		0.247		0.254
Reverb Time, second			0.28		0.29		0.29		0.31		0.29		0.28

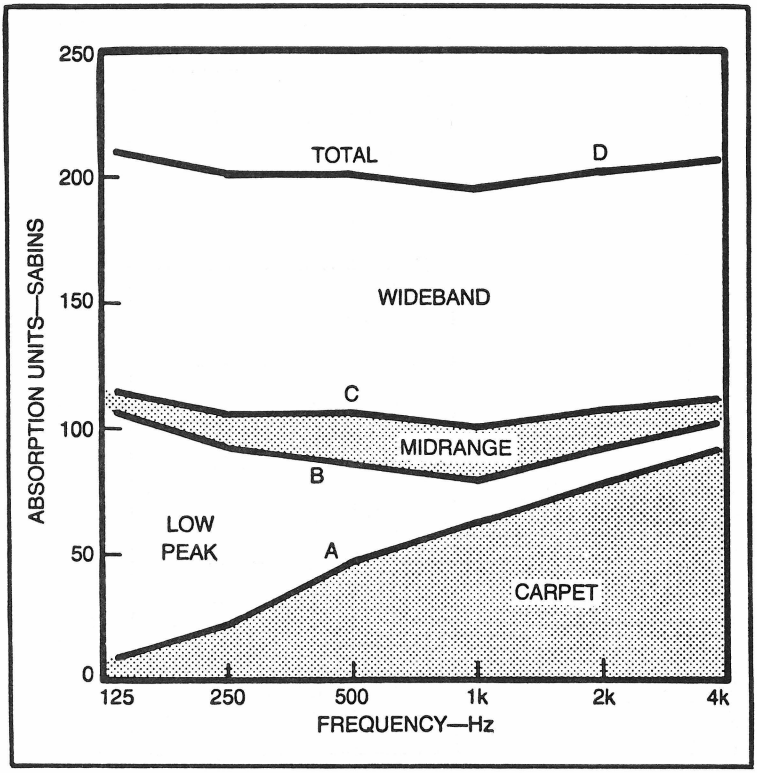


Fig. 6-5. Distribution of room absorption between the four principle types of absorbers used in treating the audiovisual recording studio.

LOW FREQUENCY UNITS

The low frequency units are most properly placed opposite the carpet for which they compensate, in the usual contracarpet position. The area required for these LF units means that 100 square feet, or 64 percent of the total ceiling area be covered with these 4 foot × 5 foot boxes, but leaving enough space for illumination fixtures. The facings of the low frequency units are quite reflective at the higher frequencies, but vertical flutter echoes are controlled by the carpet absorption.

The construction of the ceiling low frequency units is detailed in Fig. 6-7. The frame and center divider are made of 1 × 8 lumber strengthened by a backing of ½ inch chipboard or plywood. A facing of 3/16 inch tempered hardboard perforated with 3/16 inch holes spaced 2 9/16 inches on centers

covers the entire frame. In intimate contact with the perforated cover inside the box is a 4 inch thick layer of Owens-Corning Type 703 Fiberglas of 3 pounds per cubic foot density.

If the glass fiber material is loosely fitted, something is needed to hold it against the perforated facing. The 1 × 4 spacers with fine wire tacked to its edge in a zig-zag form will do this in a very positive way, but if gravity and friction can be depended upon to hold the glass fiber snugly against the back of the perforated cover, so much the easier and cheaper. The air space plays an active part in the performance of this absorber. The boxes may be mounted to the ceiling in any convenient way. Painting these units and the exposed parts of the ceiling flat black will render them visually unobtrusive, especially if the illumination fixtures direct the light downward. Track lights are ideal for this.

Hand drilling of almost 500 holes in each of the nine ceiling box covers can be a staggering job. The obvious way to minimize this is to stack all covers, drilling all with one set of

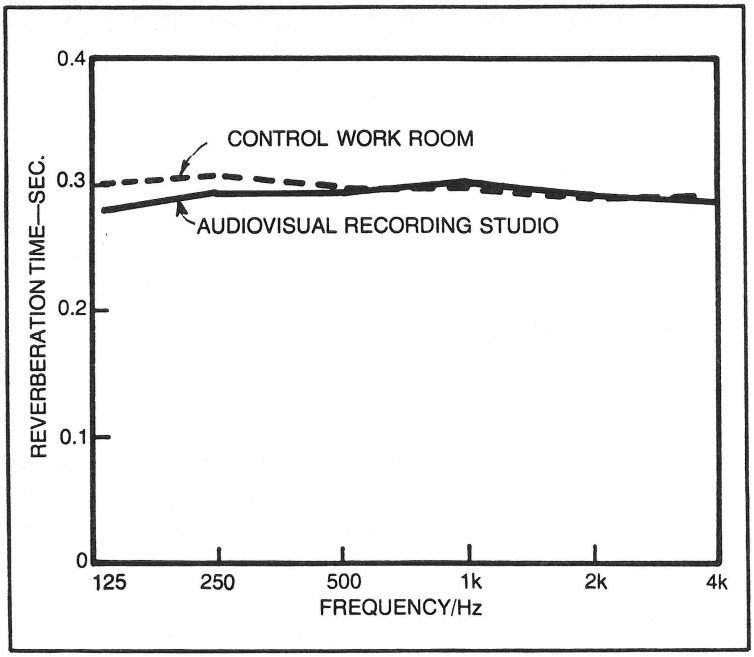


Fig. 6-6. Reverberation time of the two rooms as a function of frequency.

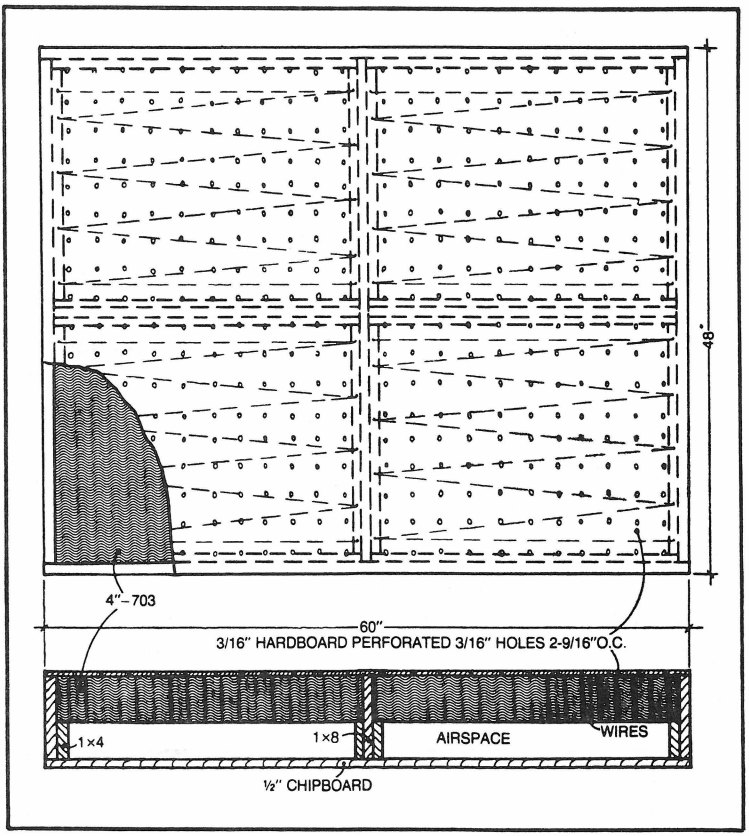


Fig. 6-7. Constructional details of the Helmholtz low frequency absorbers to be mounted on the ceiling.

holes. Each cover can be split at the center divider if desired so that 18 pieces of 30 inch × 48 inch hardboard could be stacked for drilling.

MIDBAND UNITS

The midband units have a relatively minor, but important, role to play in the overall treatment of the audiovisual recording studio as illustrated in Fig. 6-5. They are mounted on the wall under the window table and along the lower edge of the south wall in Fig. 6-3. Their simple construction is detailed in Fig. 6-8.

The covers are of Johns-Manville Transite panels which come perforated with 550 3/16 inch holes per square foot.

These are autoclaved asbestos cement boards 3/16 inch thick and their 24 inch × 24 inch size determines the size of the supporting frame. This frame is made of 1 × 3 lumber with 1 × 2 spacers inside, the 2 inch dimension should be net to accommodate the 2 inch thickness of the Owens-Corning Type 703 Fiberglas.

WIDEBAND UNITS

Acoustically speaking, the 2 foot × 4 foot wideband units are nothing more or less than 4 inches of 703 Fiberglas of 3 pounds per cubic foot density. The rest is mechanical mounting and cosmetic cover. Figure 6-9 shows how the 1 × 6 frame, 1 × 4 divider and spacers and the ½ inch chipboard back board fit together.

The manufacturer of the glass fiber stops short of attributing 100 percent absorption to 4 inches of 703, listing 0.99 as the coefficient from 125 Hz to 4 kHz.

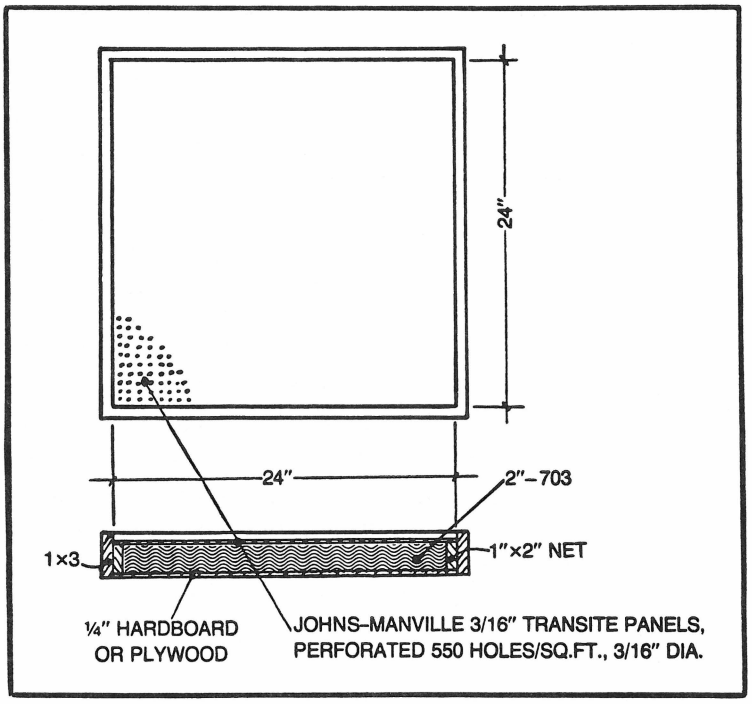


Fig. 6-8. Constructional details of the midband absorbers having peak absorption in the 500 Hz-1 kHz region.

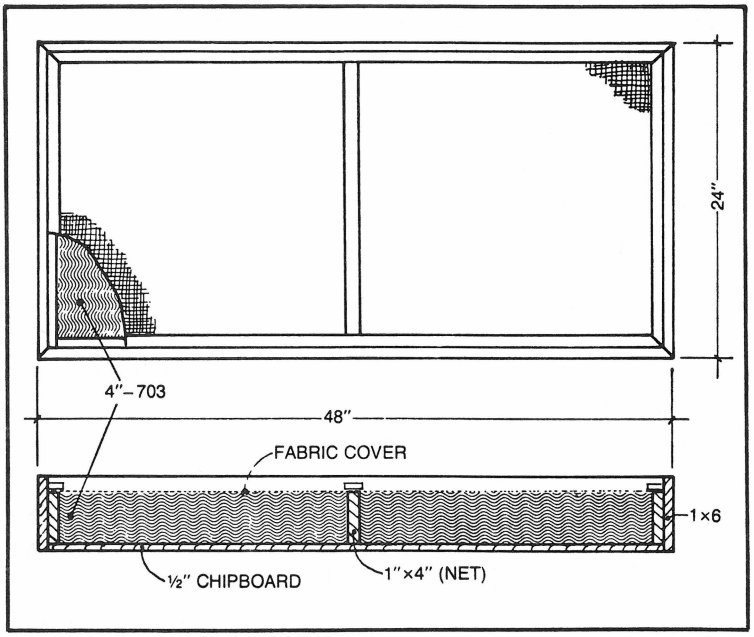


Fig. 6-9. Constructional details of the 2 foot × 4 foot wideband wall modules. These are basically 4 inches of 703 glass fiber with mechanical protection and cosmetic cover.

Below 125 Hz the absorption does fall off, of course, but in this low frequency region the diaphragmatic absorption of the five gypsum board surfaces tends to compensate. The double ⅝ inch gypsum board surfaces resonate well below 125 Hz. Calculations indicate that the walls paralleling the existing concrete walls on the north and south sides with 5 inch air space have an absorption peak at about 32 Hz. The other walls with their 8 inch air space peak near 26 Hz. These cavities are filled with insulation which increases the breadth of the absorption region markedly, but the resonance frequency little. No values of measured absorption coefficients are available for double ⅝ inch gypsum board walls with these cavity depths. However, by taking the values available for ½ inch gypsum board on 2 × 4s 16 inches on centers and shifting them to take into account the different resonance frequencies involved, an absorption coefficient of 0.05 to 0.08 is estimated for 125 Hz.

With a gypsum board area of about 580 square feet involved in the audiovisual recording studio, something like 30

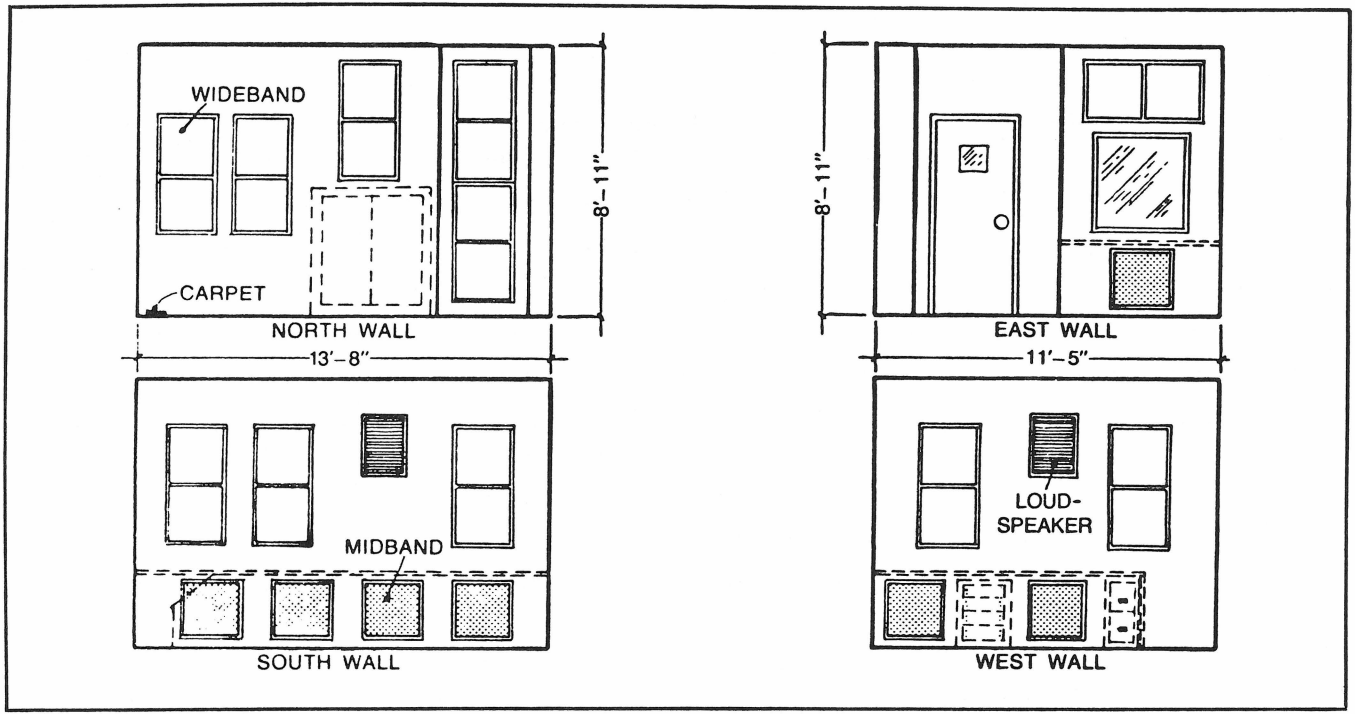


Fig. 6-10. Wall elevations of control work room showing placement of wideband and midband absorbing units.

Table 6-2. Control Work Room Calculations.

SIZE.....11'–5" × 13'–8" × 8' – 11" ceiling ht.

FLOOR.....Carpet

CEILING.....4 Low Frequency Absorbers

WALLS.....11 Wideband, 7 Midband Absorbers

SURFACE AREA.....739 sq. ft.

VOLUME.....1304 cu. ft.

MATERIAL	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	147	0.05	7.4	0.15	22.1	0.30	44.1	0.40	58.8	0.50	73.5	0.60	88.2
Low Freq. Absorb. 4–4'×5'	80	1.0	80.0	0.68	54.4	0.39	31.2	0.17	13.6	0.13	10.4	0.10	8.0
Midband Absorbers 7–2'×2'	28	0.35	9.8	0.63	17.6	0.88	24.6	0.84	23.5	0.66	18.5	0.35	9.8
Wideband Absorbers 11–2'×4'	88	0.99	87 1	0.99	87.1	0.99	87.1	0.99	87.1	0.99	87 1	0.99	87.1
Total sabins, Sa			184.3		181.2		187.0		183.0		189.5		193.1
Ave. Absorp. Coeff., a			0.249		0.245		0.253		0.248		0.256		0.261
Reverb Time, second			0.30		0.31		0.30		0.30		0.29		0.29

to 40 additional sabins may be at work at 125 Hz because of wall absorption. This would reduce the reverberation time at 125 Hz to something like 0.23 second and be less effective than this at 250 Hz and above. This possible 23 percent reduction of reverberation time at 125 Hz requires measurements to tie it down specifically, but this discussion points out that such wallboard absorption might reduce the required area of ceiling low frequency absorbers.

CONTROL WORK ROOM TREATMENT

The control work room is treated with the identical four elements as the audiovisual recording studio: carpet, wideband and midband wall units and ceiling mounted low frequency absorbers. Figure 6-10 shows the suggested placement of each unit on the walls and Fig. 6-4 B the placement of the four low frequency units on the ceiling. Table 6-2 lists vital statistics of this room as well as the absorption units (sabins) expected of each of the four elements at each of the six frequencies.

There is little need to plot the contribution of each of the four elements. Although the values differ somewhat, the general apportionment principle revealed in Fig. 6-5 for the audiovisual recording studio applies to this room as well. The calculated reverberation times of Table 6-2 are plotted in Fig. 6-6 for ready comparison with those for the other room.

Chapter 7
Multitrack in a Two Car Garage

Feature: Get maximum track separation in a minimum space.

There has been a proliferation of small studios in basements, barns, garages and other locations in and around private residences. Some of these are built by the members of new bands who figure that such a facility would help them develop their musical techniques and enable them to record demonstration and other records at leisure without high studio charges. Some are built by advanced audiophiles who have become jaded to further improvements in the living room hi-fi, but really are challenged by recording techniques. Such a private studio is a logical next step after experimenting with multichannel recording with a four track consumer type tape recorder. This type of experimentation soon runs headlong into the frustrations of household noise, limitations in the number of tracks and problems created by haphazard, temporary lashups.

Some may look to a private recording studio as a stepping stone to getting into professional recording. As far as gaining experience is concerned, excellent, but if renting the studio to musical groups is contemplated, beware. Most communities look with disfavor on commercial activities in residential areas. Construction of the studio to be described in this chapter definitely requires a building permit and the usage

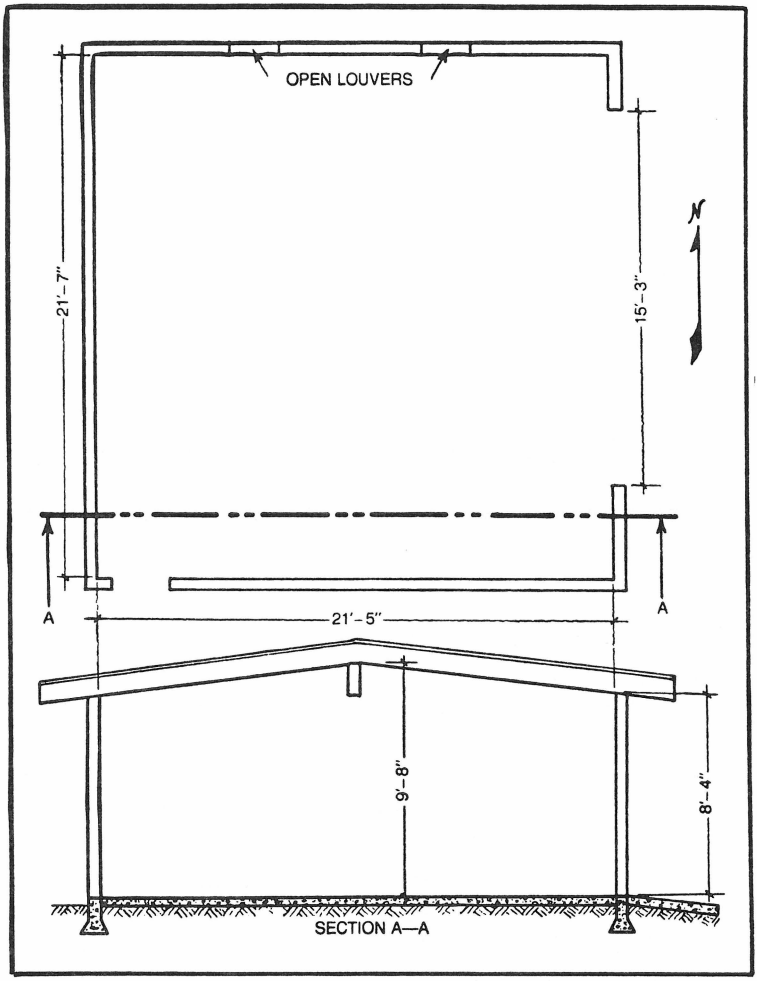


Fig. 7-1. Plan and sectional views of garage before its conversion to a multitrack recording studio.

planned for the facility is sure to come up. Now that this point has been made, it is possible that the studio does have limited commercial possibilities. The greater the experience one has, the greater the emphasis on that word limited.

FLOOR PLAN

The two car garage to be converted into a multitrack studio is described in Fig. 7-1. It is almost square and is covered with a simple A-roof. The open ventilation louvers in

the north wall, a 15 foot-3 inch overhead door opening in the east wall and a small rear door in the south wall emphasize that the garage is just a wide open shell with unfinished walls inside.

The first step is to make the garage into a tight structure and to make provisions for a monitor control room. Figure 7-2 shows one way of distributing the 464 square feet of total area between the studio and control room. This gives a studio floor area of 352 square feet and a control room area of only 85 square feet. The studio size is over twice the minimum prescribed volume of 1500 cubic feet but the control room is only about half the minimum.

This may be sufficient incentive to drive the recording technician to using high quality headphones instead of monitor loudspeakers. The fact is that with a square garage, any location for the control room other than a corner results in

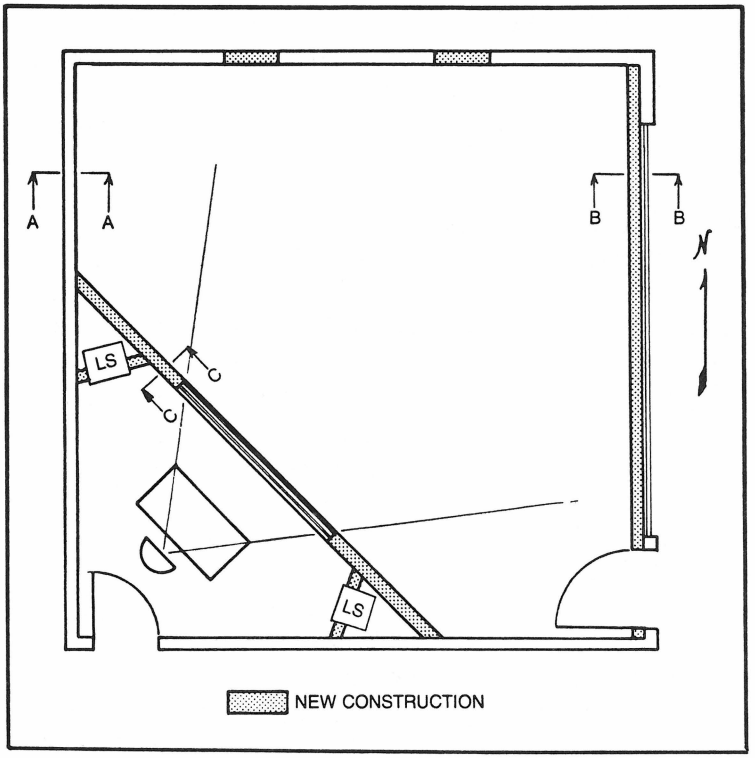


Fig. 7-2. Plan for conversion of garage of Fig. 7-1 to a multitrack recording studio.

serious degrading of studio space. The floor plan of Fig. 7-2 favors the studio. Perhaps that demo record may have greater impact with a reasonable studio and operator wearing headphones than a tiny studio with its poor separation and more accurate monitoring room.

The use of high quality headphones, [12, 15] if not a first choice, is at least a viable alternative for listening critically in acoustically difficult situations. They are being improved much faster than monitoring loudspeakers.

The louver ventilators in the north wall are abandoned and the opening framed in and covered to conform to the other external walls. The overhead door probably should be retained for external appearance, although the bulky hardware may be removed and stored for possible future use. A new frame closes off the 15 foot-3 inch door opening. A door (3 feet wide to accommodate instruments) is cut in the east wall for access to the studio. This should be a 1-¾ inch solid core door and well weatherstripped. The sound lock corridor in this case is the great outdoors. The existing doorway in the south wall serves the control room, but the hollow core door is replaced by a 1-¾ inch solid core door and also weatherstripped.

WALL AND CEILING CONSTRUCTION

The internal wall and ceiling surfaces are covered with ⅝ inch gypsum board as shown in Fig. 7-3. Great care should be exercised to assure tightness as this layer is the chief assurance against complaints from the neighbors. This requires filling of all cracks and taping of all joints as well as a liberal use of non-hardening acoustical sealant at all intersections of surfaces. This drywall layer goes in the control room as well as the studio. The diagonal wall between the studio and the control room has a ⅝ inch gypsum board on each side as shown in Fig. 7-3, Section C-C.

The conversion of this garage to a studio is fraught with compromises. The result will be something like midway between the living room and a first class studio. The wall between the studio and control room is such that studio sounds will sometimes be heard in the control room without benefit of amplifiers and loudspeakers. Neighbors can probably hear a

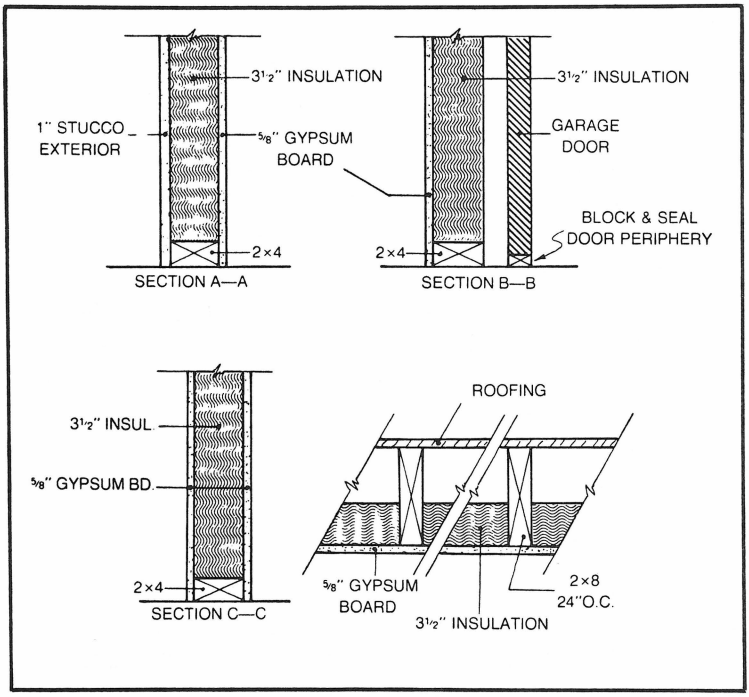


Fig. 7-3. Wall construction details in converted garage studio. Sections refer to Fig. 7-2.

lively number being played in the studio, but hopefully at a low enough level that they will not call the police.

Unless the two single doors are made impervious to sound passing them, there is little advantage in strengthening the walls. A good, tight wall such as shown in Section C-C of Fig. 7-3 has an STC rating of 30 to 35 and the stucco plaster of Section A-A is only slightly better. Great care must be exercised in weatherstripping doors to get STC 30. The 3½ inches of insulation fill indicated in all sections of Fig. 7-3 contributes very little (about 2 dB) to the transmission loss. It does help some in discouraging cavity resonances. Because of its minor effect, it could be omitted if the budget is very tight.

STUDIO TREATMENT

Multitrack recording requires acoustical separation of the sounds of instruments or groups of instruments which are recorded on separate tracks. One way of achieving such sep-

aration is to physically separate the sources and place a microphone close to each source. Space is limited in this studio, but this logical and desired approach is more effective in an acoustically dead space than in a live one. There are other ways separation can be achieved, such as the use of microphone directivity, baffles, etc.[13].

Acoustical Goals

Musician reaction places a limit on the deadness of such a studio because they must hear themselves and other musicians to play effectively. The studio of Fig. 7-4 has been made as dead as practical to allow the achievement of reasonable track separation, even though the space is small for this type of recording.

Floors and Ceiling

Heavy carpet and pad are applied to the entire concrete floor except the drum booth area. This opposes the sloping, reflective ceiling surfaces which are bare gypsum board. Reflections from this ceiling could contribute to leakage between tracks. If this proves to be a limiting factor, absorbent material could be applied to critical areas of the ceiling.

WALLS

Much of the wall is faced with 4 inches of 703 type of semirigid glass fiber boards. These glass fiber panels are inserted between vertical 2 × 4s which are mounted against the gypsum board wall covering and run from floor to ceiling. Figure 7-4 shows the 2 × 4s spaced 16 inches center to center, lined up with the studs of the exterior wall to which they are nailed. After the glass fiber is installed between these inner studs, a fabric cover is stretched over all, tacked in place and finished strips nailed on the edge of each 2 × 4 to complete the floor to ceiling job. The south half of the east wall and the south wall are left reflective to provide an area in the southeast corner of the studio, near the door, which would have somewhat brighter acoustics than the other areas near absorptive walls. Such localized acoustics can be of great help in instrument placement.

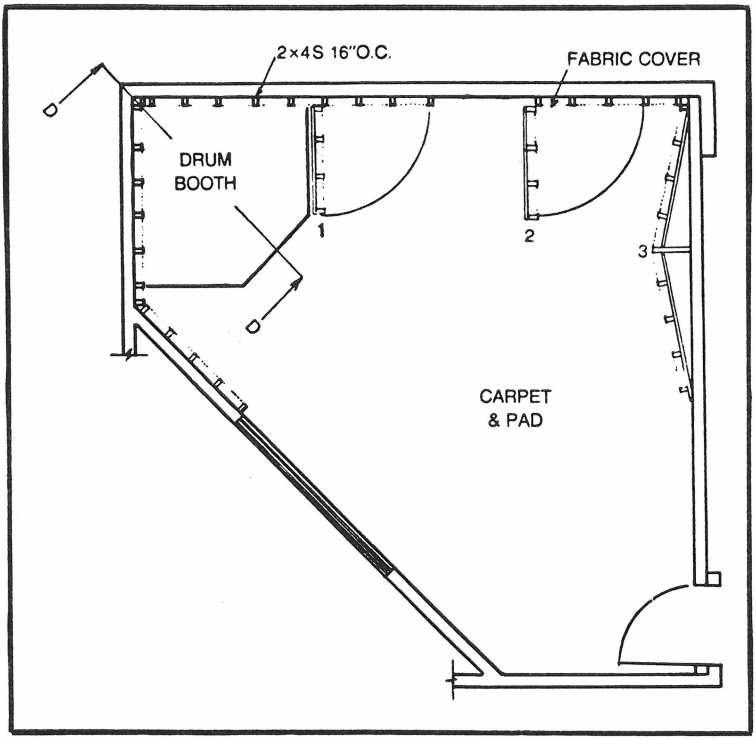


Fig. 7-4. Studio details in garage converted to multitrack studio. Swinging doors 1 and 2 serve as baffles between instruments. Element 3 on east wall helps to absorb very low frequencies.

On the north wall are two swinging panels 4 feet wide running from an inch above the carpet to a height of 6 feet to 8 feet. These panels are framed of 2 × 4s with ¾ inch particle board or plywood backs for strength holding 4 inches of 703 glass fiber covered with fabric like the walls. The back of panel 1 in Fig. 7-4 in open position, presents the drummer with his only reflective surface apart from the floor. The space between swinging panels 1 and 2 can be between panel 2 and the east wall can be occupied by a second. Others will have to be positioned in the open area.

On the east wall the same 2 × 4 framing filled with 4 inches of 703 is followed except that here a space behind is provided to augment absorption in the very low frequencies (element 3). At these frequencies the sound penetrates the 4 inches of glass fiber, causing the ¾ inch plywood or particle

board to vibrate as a diaphragm, absorbing sound in the process. It may be found that the instrumentalist in space 1 is too close to the high level drum sound. It would be quite acceptable to move the low frequency element to the north wall and the instrument alcoves 1 and 2 to the east wall if this would meet separation needs better. Such a move would increase the distance between instrumentalists (and their microphones) and the drum kit. Barriers 1 and 2 would provide separation only between instruments, not between instruments and drums unless more complicated double hinged panels were installed.

DRUM BOOTH

The corner area for the drum booth is indicated in Fig. 7-4. The concrete floor of the booth is left bare under the drums to give the desired effect. Another reflective surface for the benefit of the drummer is the surface of swinging panel 1. Apart from these, all surfaces around the booth are highly absorptive to contain the drum sounds and thus improve separation from the sounds of other instruments.

Without adequate separation the advantages of multitrack recording disappear. There is general agreement on two points:

- That sounds from the drumkit are hard to contain.
- A good drum sound is basic to any group.

This is justification for doing something extra for the drummer, even in a budget facility such as this. It would be nice if we could do the same for the vocalist.

Leaving the bare ceiling over the drum booth would defeat the whole purpose of the booth. Drum sounds must be absorbed rather than allowed to float over the entire area. A canopy of 2 × 4 framing is dropped down from the ceiling to a point 6 feet above the concrete floor as shown in Fig. 7-5. The shape of this canopy follows the general drum booth front edge shown in Fig 7-4.

The face of the canopy toward the studio is covered with a double layer of ⅝ inch gypsum board, but the inside of the entire 2 × 4 framing on 16 inch centers is left open to receive 4 inches of 703 glass fiber board.

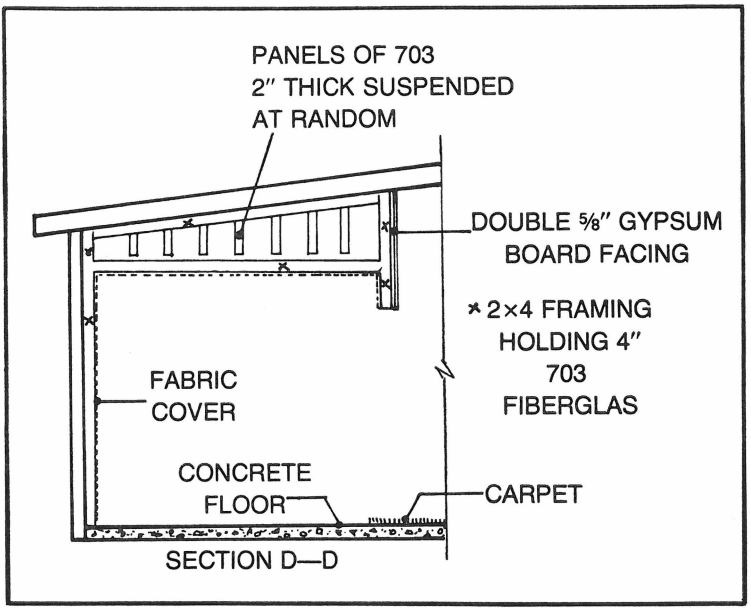


Fig. 7-5. Section of Fig. 7-4 through the drum booth. All drum booth surfaces except the concrete floor are highly absorbent to contain drum sounds.

A fabric cover is then applied and held in place with finished strips nailed to the 2 × 4s. This 4 inches of 703 treatment faces the drummer on all sides including walls, underside of canopy and inside of canopy lip. The construction leaves an *attic* between the canopy ceiling of 4 inches of 703 and the 4 inches of 703 affixed to the uppermost ceiling gypsum board. Because drums have a hefty low frequency content, the attic can be made into an effective absorber for very low frequencies, frequencies lower than the 4 inches of 703 can handle. The term *basstrap* has been applied to such absorbers. Such a catchy term, which seems only to confuse the populace, will not be generally used in this book, at least until *trebletrap* is accepted to describe the acoustical effect of carpet. Low frequency absorbers, however, do come in varying degrees of *lowness*. The 4 inches of 703 is essentially a perfect absorber down to 125 Hz and its absorbing effectiveness decreases as frequency is lowered. For this drum booth attic, a trick of the builders of early anechoic, *free-field chambers* or *dead rooms* is used. This is the hanging of spaced absorbing panels to extend the useful low frequency range of

the room. The spacings of the panels of 2 inch thickness 703 may be random rather than following meticulous rules used in those early day.

COMPUTATIONS

Reverberation time, of itself, does not play too important a role in multitrack recording because our primary goal is adequate track separation. Some hyped-up sound, not naturalness, is the goal of rock recording. Following through on the computations of Table 7-1, however, gives a good feel for comparing treatment of this type of studio with the more traditional speech and music studios. The drywall, carpet and 4 inches of 703 areas are estimated. The extra bass absorption effect of the drum booth attic and the structure on the east wall are neglected as their effect over and above that of the 4 inches of 703 is largely below 125 Hz, the lowest frequency of Table 7-1.

The calculated reverberation times of the studio range from 0.25 to 0.16 second as compared to 0.35-0.60 second if the same studio were treated for recording speech and traditional music (Fig. 7-6). This comparison emphasizes the general deadness of multitrack studios in the quest for track separation.

Studio deadness, of course, is not the only step toward adequate track separation. The use of baffles, microphone directivity, close placement of microphones and other factors have their important effects.

CONTROL ROOM TREATMENT

Figuring the axial mode frequencies of a triangular room is far beyond the scope of this book but the average ceiling height of about 9 feet would yield a fundamental of around 60 Hz and the others would not be too far from this. Cutting off the sharp corners near the window provides a shelf for the loudspeakers. To remove the bad effects of the cavity in which the loudspeakers sit, a heavy plywood baffle should be fitted around the face of the loudspeaker (Fig. 7-7).

The triangular space below the loudspeaker may be utilized as a low frequency absorber to help counteract the

Table 7-1. Studio Calculations.

SIZE ..... 21′–5″ × 21′–7″ with corner cut
FLOOR ..... Carpet and pad (except for drum booth)
CEILING ..... ⅝″ gypsum board
WALLS ..... ⅝″ gypsum board, partially covered with 4″ 703
SURFACE AREA .... 1,550 sq. ft.
VOLUME ..... 3,170 cu. ft.

MATERIAL	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Drywall	1,000	0.1	100.	0.08	80.	0.05	50.	0.03	30.	0.03	30.	0.03	30.
Carpet	310	0.05	15.5	0.15	46.5	0.30	93.	0.40	124.	0.50	155.	0.60	186.
4″ 703	500	0.99	495.	0.99	495.	0.99	495.	0.99	495.	0.99	495.	0.99	495.
Total sabins, Sa			510.5		621.5		638.0		649.0		680.0		721.0
Average absorption coeff, a			0.329		0.401		0.412		0.419		0.439		0.465
Reverberation time, sec.			0.25		0.20		0.19		0.18		0.17		0.16

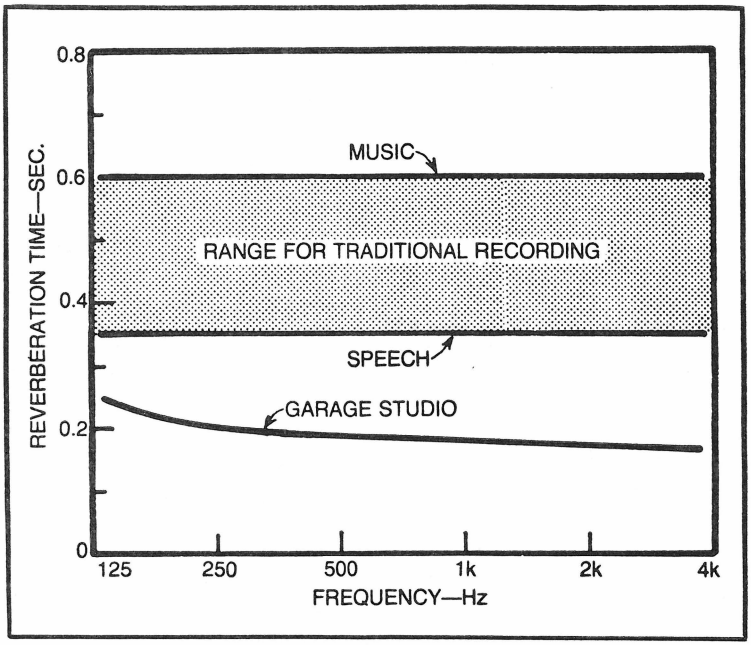


Fig. 7-6. The reverberation time of the garage multitrack studio is far shorter than that for more traditional recording.

carpet effect. To coin a euphonious phrase, this is a slit resonator utilizing the slots between the slats and the cavity behind. It is made simply of 1 × 4s spaced about ¼ inch with 2 inches of 703 pressed against the rear of the slats. The cavity itself serves only to contain the springy air.

On the walls behind the operator about thirty 12 inch × 12 inch × ¾ inch acoustical tiles are cemented to each wall in a 6 × 5 array. This totals 60 square feet. Carpet covers the floor and the ceiling is drywall. The two resonators plus some 350 square feet of gypsum board compensate for the low frequency deficiencies of the tile and carpet, but not completely. This brings the reverberation time of the control room to about 0.34 second, rising to about 0.46 second below 250 Hz. With all the compromises involved there seems to be little justification for further acoustical adjustment.

Outside Noise to Inside

No matter how high the average and peak levels of music are in the studio, there are those soft, sweet and sentimental

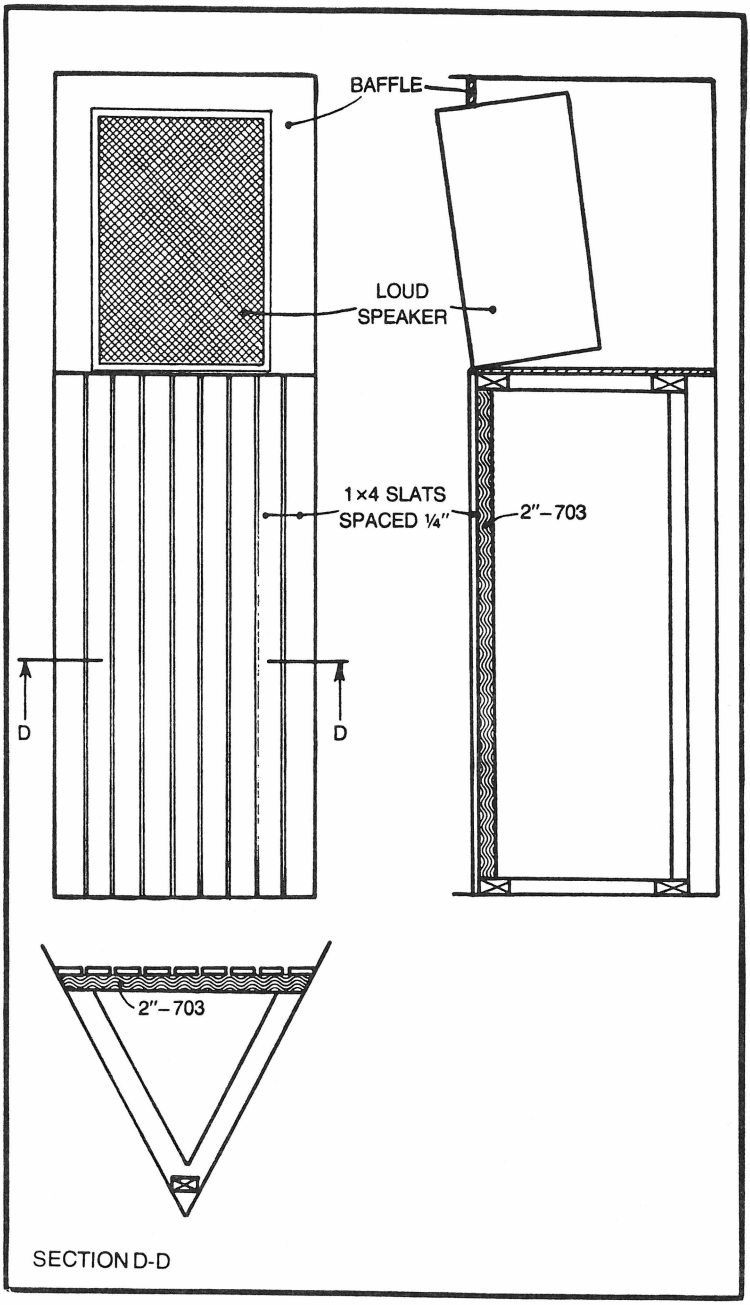


Fig. 7-7. Corner treatment in control room of garage multitrack studio. Helmholtz resonators having a peak of absorption in the low frequencies are built into the corners. These are slat type resonators.

passages for contrast. The barking of a neighbor's dog heard on the vocal track during such a passage is guaranteed to raise the emotional level even higher than the vocalist could hope for. Therefore, concrete walls 6 feet thick are longed for at such times, but they are just too expensive.

The simple walls of Fig. 7-3 are all this budget could stand. Statistics are on the side of the amateur or low budget recording job. How often do soft passages occur? How often do screaming motorcycles or other interfering noises occur? The permutations and combinations are such that redoing a very occasional ruined take is usually the answer for this type of studio. However, it is quite a different story if it costs $5,000 in studio time and for talent to redo the passage.

Inside Noise to Outside

Very square neighbors have been known to identify that beautiful stuff being layed down in multitrack within the studio as noise. The difference in point of view can bring the police. In some communities the noise ordinance is as broad and general as this one:

> "It shall be unlawful for any person to make, cause or permit to be made, any loud or unusual noise which directly causes an unreasonable interference with the use, enjoyment and/or possession of any real property owned or occupied by any other person."

In an increasing number of communities a certain maximum allowable noise level is set for the boundary of the property on which the studio rests. In brief, the sounds escaping from the studio may give far more trouble than exterior sounds spoiling takes. Walls offer the same transmission loss both ways and the walls of Fig. 7-3 are certainly minimum with respect to noise going either way.

Multitrack Recording

Multitrack recording techniques require studios quite different from the traditional kind. Numerous books have been written on the multitrack subject [12,16-18] as well as many articles in the technical press [19-29]. The reader is referred to them for information on the host of pertinent points which cannot be covered in this book.

Chapter 8
Building A Studio From Scratch For Radio Program Production

Feature: Adjustable acoustics, service areas, splayed walls.

Many small studio projects must be warped around to fit into space in an existing building. This means compromises, compromises. When this particular client said that the studio building was to be built from the ground up, the news was received with delight. That was the good news, then came the bad news: the new building was to be jammed between existing buildings on two sides and a brick wall on the third side. But even this means a certain amount of shielding from exterior noise by these masonry structures.

The space available was 18 × 6 meters (the site is in a foreign country) or about 59 feet–0 inches × 19 feet–8 inches. This was taken as the outside dimensions of the building. Besides a studio and control room, space was required for tape and film storage, toilet facilities and an office.

The floor plan of Fig. 8-1 was developed with some give and take. Walls of spaced double brick tiers were specified to surround the studio and control room as protection against outside noise. The studio size and shape was the first task. What maximum studio length could best fit a maximum inside width of 18 feet with a practical, economical ceiling height?

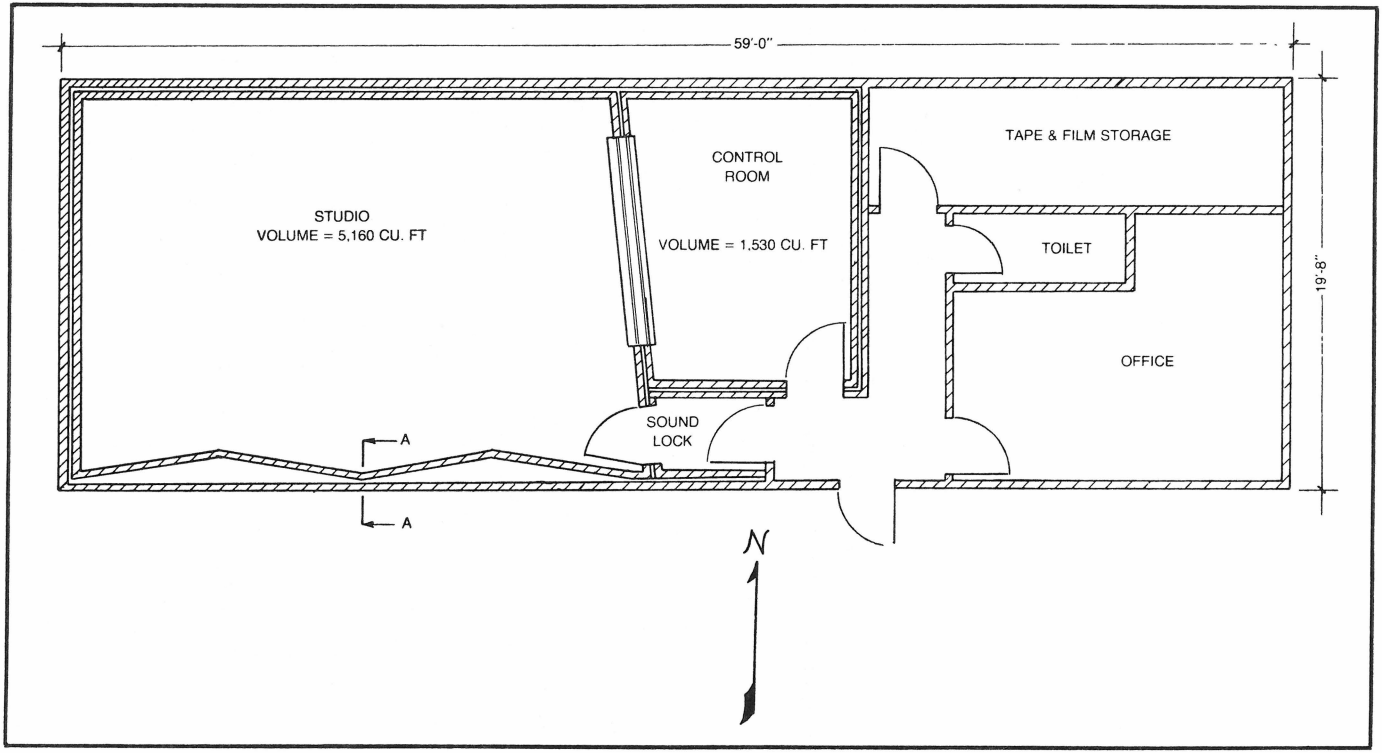


Fig. 8-1. Floor plan of studio complex which includes service areas as well. Splayed east and south walls help control flutter echo.

Several factors were considered: one variable (length); one constant (width); and one variable with definite constraints (ceiling height).

When the opportunity to splay two of the four walls presents itself, as it did in the present case, it is wise to do so. This eliminates (or at least reduces) the chance for flutter echoes between parallel surfaces.

Placement of acoustical materials can also reduce flutter echoes, but if it can be done with geometry independent of the acoustical treatment, a greater degree of flexibility accrues in the placement of such materials.

The east wall containing the control room window was inclined at about 5 degrees from its rectangular position as shown in Fig. 8-2. The south wall was given two triangular protuberances with sides inclined 8.6 degrees. Any angle between 5 degrees and 10 degrees will usually prove sufficient for control of flutter echo. This inclining of wall surfaces takes care of the N-S and E-W flutter modes. The vertical mode

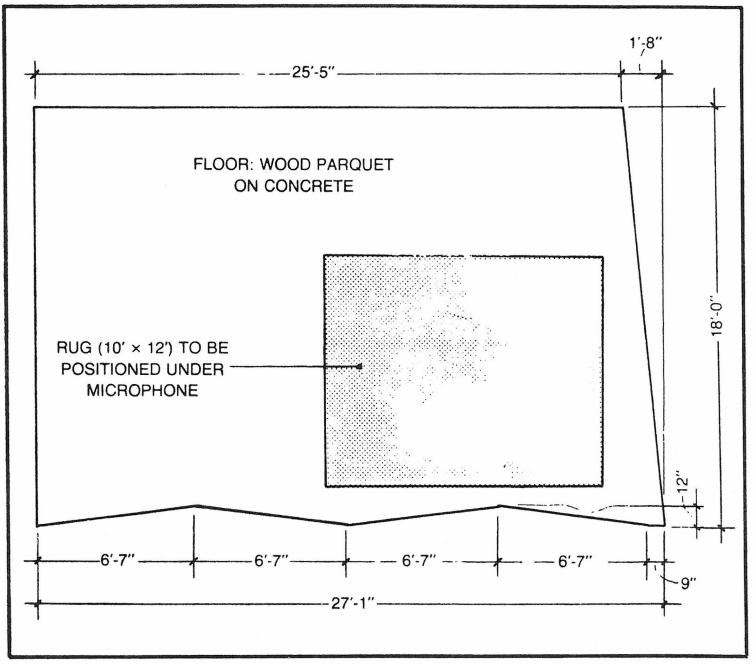


Fig. 8-2. Splaying plan of studio. The splaying angles are about 5 degrees (east wall) and 8.6 degrees for the triangular south wall.

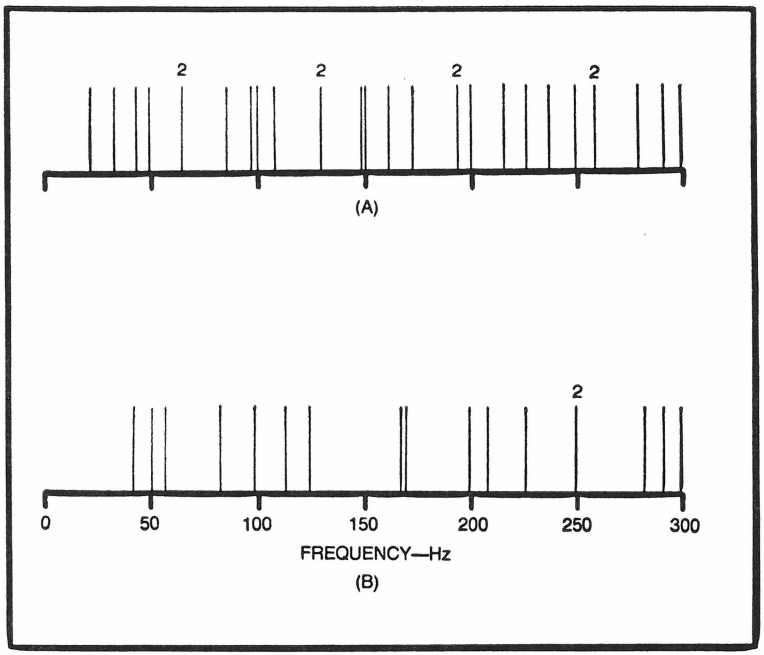


Fig. 8-3. Distribution of axial room resonance frequencies for (A) studio and (B) control room. Note that for the larger studio the average modal spacing is about 11 Hz; for the control room about 16 Hz. The small 2 indicates two resonances which are coincident.

flutter could be cared for by constructing wrinkles of some sort in the ceiling (or the floor!) but other methods will be used.

DISTRIBUTION OF MODAL RESONANCES

Again, considering only the axial modes of the studio and disregarding the less influential tangential and oblique modes, let us select studio length and ceiling height which will give reasonable distribution of room resonances. With a splayed east wall and a south wall broken up by four splayed surfaces, the average length is taken to be 26 feet–3 inches and the average width 17 feet–6 inches. With a height of 11 feet–3 inches, the distribution of modal resonances is as illustrated in Fig. 8-3A.

One very great advantage of a larger studio is that the average spacing of room resonances is reduced. The average spacing of resonances in this studio (5160 cubic feet) is 11 Hz.

The average spacing of resonances in the 1530 cubic feet control room (Fig. 8-3B) is about 16 Hz. This closer spacing, if not too close or coincident, tends toward fewer colorations, thus better quality.

The small numeral 2 above certain room resonance lines in Fig. 8-3 indicates a coincidence of two modes at that frequency. We may disregard the two coincidences in the studio at higher frequencies and the one at 65 Hz because of the BBC experience that audible colorations are rare in those frequency regions[6]. This leaves the coincidence at 129 Hz and the close pair near 150 Hz as possible threats.

In the control room (Fig. 8-4) coincidences at 249 Hz are high enough to not cause concern. The close pair at 166/169 Hz is aggravated by wide spacings on each side. As sound

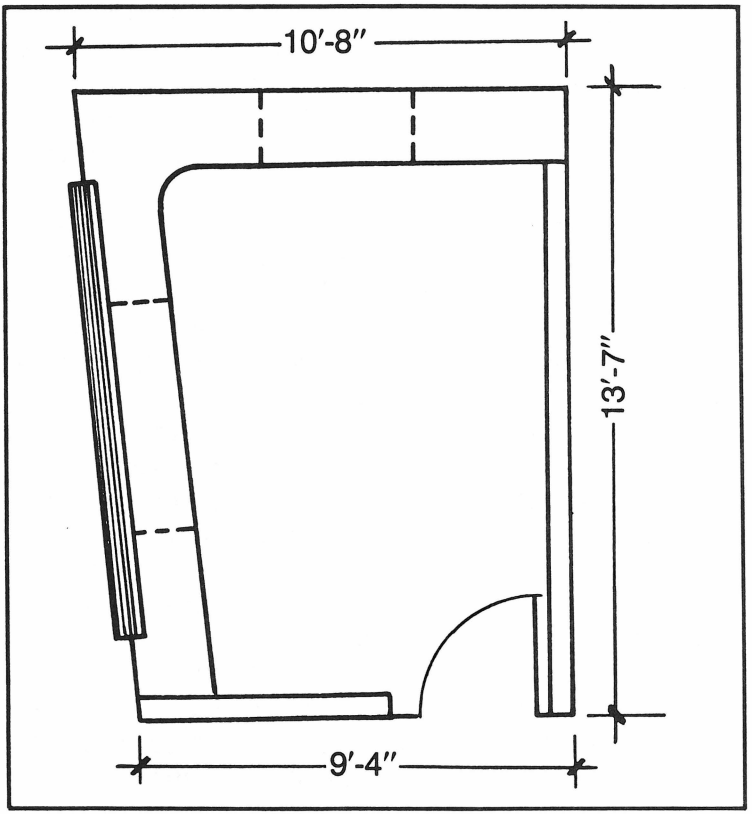


Fig. 8-4. Floor plan of control room. Built-in work surface extends the length of two walls.

decays in the room these two could beat together at a 3 Hz rate.

Other factors must be favorable before coincidences result in observable colorations, hence they may or may not be troublesome. It is impractical to push further an analysis such as this; suffice it to say that there is the advantage of a warning of potential problems at 129 Hz and 150 Hz in the studio and 166/169 Hz in the control room.

NOISE CONSIDERATIONS

How heavy should the walls be made? In general, the heavier the walls the better protection offered against external noise. On the other hand, the heavier the walls the greater the cost. In the present case, brick, a favored and economical local building material, seemed both logical and economical for walls. The question is, single tier wall or double tier?

The answer is to be found in two categories, (a) the level of environmental noise at the studio site and (b) the level of noise allowable inside the studio. The walls (and other parts of the enclosure, such as doors) are called upon to reduce (a) to (b).

The hoped for lowness of studio noise may be expressed by selection of a standarized noise contour. In this example the N-15 contour was selected which is the lower curve in Fig. 8-5. This is a reasonably stringent requirement. Studio noise levels somewhat above this (e.g., N-20) would not seriously impair most types of recording.

A lower background nosie level is required for mono recording than for stereo. As this studio is engaged only in mono recording at present, with plans to convert to stereo in the future, it seemed wise to select the more conservative N-15 criterion. Because of the increase in sensitivity of the human ear as frequency is increased, the N-15 contour has its characteristic downward slope.

Evaluating the environmental noise at the studio site in any specific, direct way is a rather complicated procedure. This noise is usually anything but steady, having peaks and low points between peaks. There is usually a variation with time.

This studio is located behind an office building, about 100 feet from a city street carrying typically heavy downtown traffic. Because actual around-the-clock measurements were

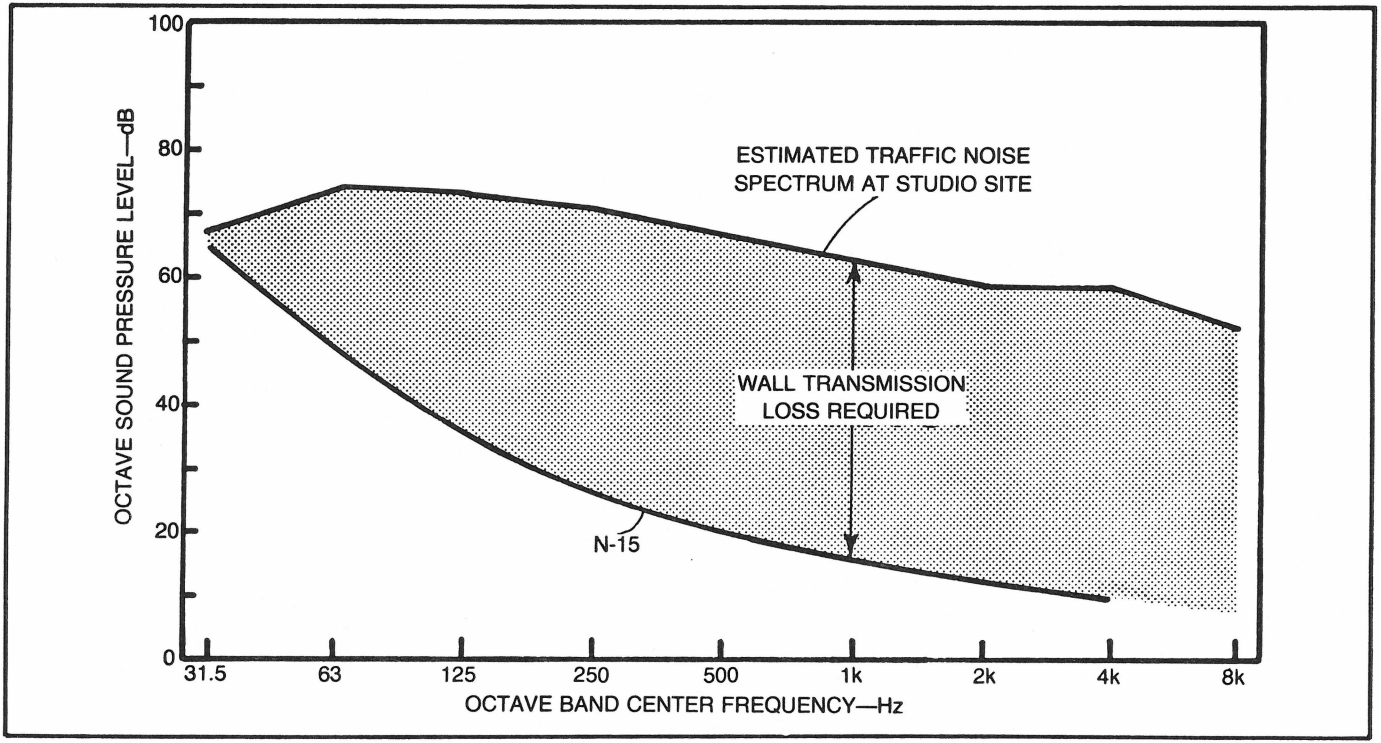


Fig. 8-5. Studio wall requirements are based on the environmental noise level at the site and the noise contour selected for inside the studio. The shaded area between these two curves represents transmission loss which the walls must provide.

not feasible, similar measurements made by others and reported in the literature were used as the basis of estimation.[30] This procedure gives the upper curve in Fig. 8-5. The shaded area between the two curves represents the transmission loss which the walls must give to reduce the exterior noise to the N-15 level in the studio.

The differences between the two curves of Fig. 8-5 at selected frequencies gives the transmission loss required which is replotted as the heavy line in Fig. 8-6. Adequate data on the transmission loss of brick walls is difficult to find, but a paper published in Europe[31] gives measurements on single and double tiered brick walls which are adapted in Fig. 8-6.

The double tiered brick wall has one face cement plastered, the single tiered wall has no plaster. If the transmission loss offered by these brick walls is greater than the transmission loss required, well and good. If below, the walls are falling short of the requirement. In Fig. 8-6 the single brick wall falls far short of the required loss from about 100 to 1,000 Hz. The double brick wall is considerably better, falling short a maximum of only 6 dB between 100 and 400 Hz. The site noise level and the selection of the N-15 contour are not precise enough to make much of a fuss about this 6 dB.

Further, plastering both the exterior and interior faces of the double brick wall will increase its transmission loss to the point where the 6 dB difference is partially made up. The conclusion, then, is that a double brick wall, plastered on exterior face and studio face, should bring the studio background noise level to about the N-15 contour, a satisfactory level for the recording work contemplated.

WALL CONSTRUCTION

Figure 8-7 is Section A-A of Fig. 8-1. It shows one method of supporting the ceiling joists on the inner tier of bricks. Solid ties between inner and outer brick tiers, intentional or otherwise, seriously degrade the transmission loss of the wall. Local codes may require such ties, but they should be used as sparingly as possible or not at all.

In building a studio from the ground up there is the opportunity of including flutter echo insurance with no significant increase in cost. The inner brick wall is built into triangular

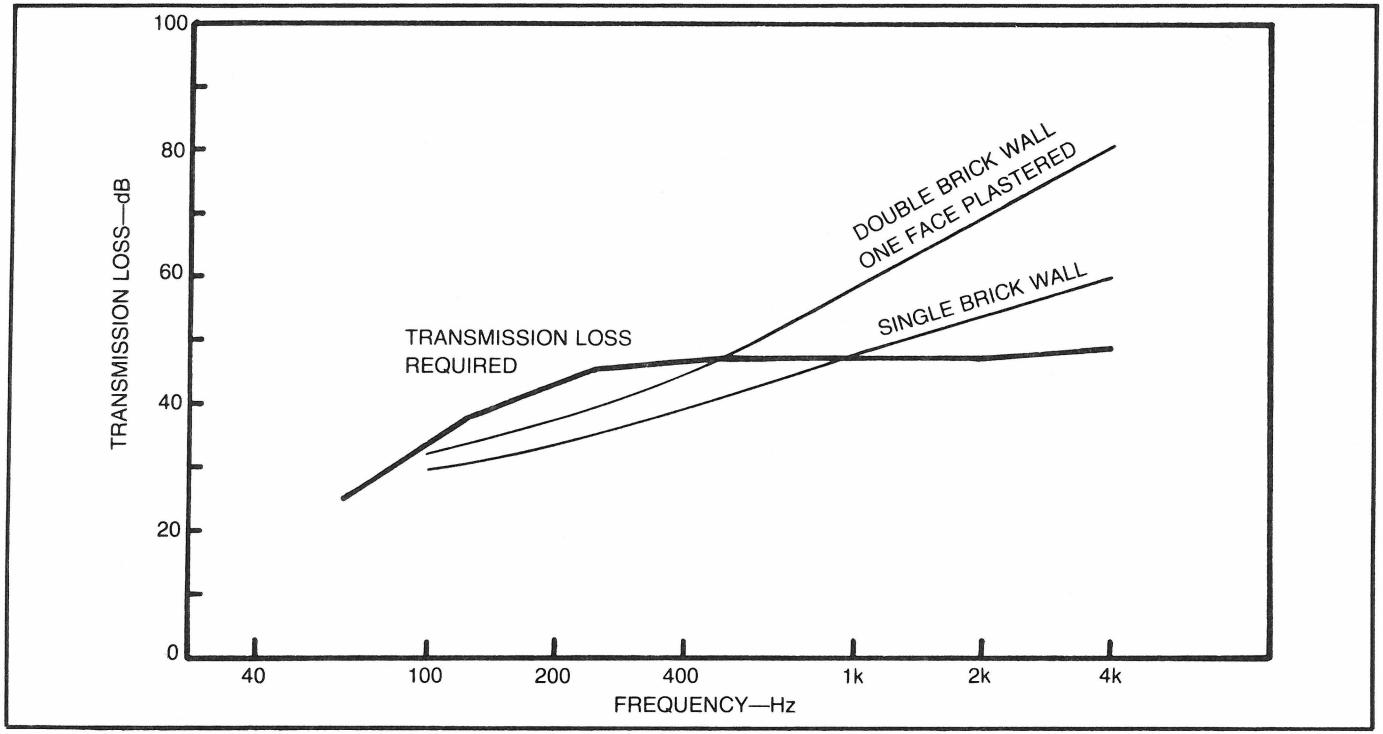


Fig. 8-6. The transmission loss required curve is obtained from the number of dB separation between the two curves of Fig. 8-5. The transmission loss offered by different types of wall construction may then be compared to that loss required.

shapes on the south wall and the splayed east wall helps both the studio and the control room.

SOUND LOCK

The normal studio layout would open both studio and control room doors into the sound lock. In the present case high control room traffic resulted in the decision to open the control room into the entrance lobby (Fig. 8-1). It must be recognized that this somewhat negates the double east wall of the control room as the single control room door will give only some 30 dB isolation, compared to something like 50 dB for the wall. Office noise may be a greater threat than exterior noise.

STUDIO FLOOR

The floors of the studio are specified to be covered with wood parquet. This is a beautiful floor covering which is ruled out by high cost in many areas, but not in this one. This is a highly reflective floor as far as sound waves are concerned. It is opposed by a highly absorbent ceiling to be described later. A microphone placed near any reflective surface receives both a direct component of sound from the source and another reflected from the surface. The latter arrives later and creates comb filter distortion in the electrical signal obtained from the microphone.[32] For a close source, the 10 foot × 12 foot rug under the microphone and source will minimize this form of distortion. For a distant pickup the microphone should be placed very close to the floor so that the two path lengths are approximately equal, or on a stand so that the bounce takes place on the other end of the rug.

STUDIO WALLS

Three types of wall treatment (Fig. 8-8) are utilized in the studio:

- wideband (WB) absorbers.
- acoustical tile.
- low frequency (LF) absorbers to compensate for low frequency deficiencies in WB absorbers and acoustical tile, especially the acoustical tile.

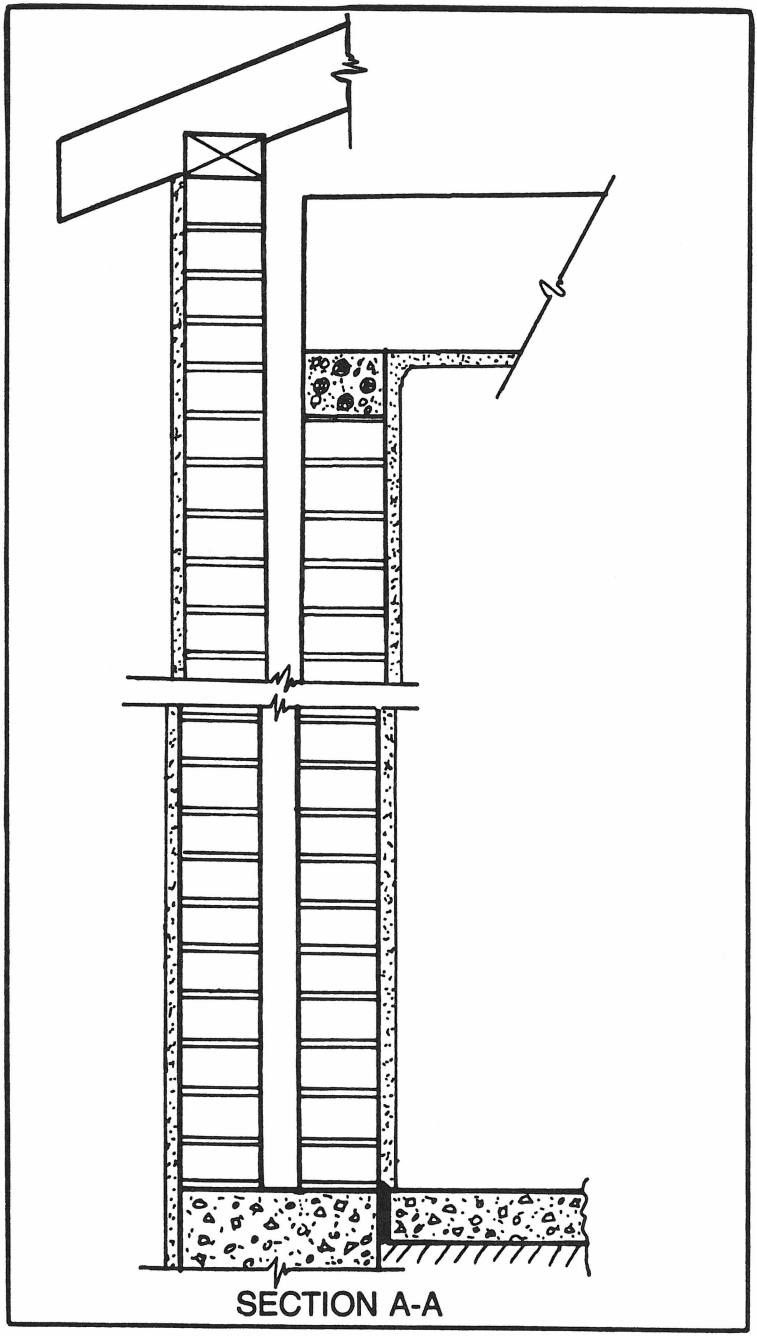


Fig. 8-7. Studio wall construction of double tier brick, plastered inside and out. Section A-A specified in Fig. 8-1.

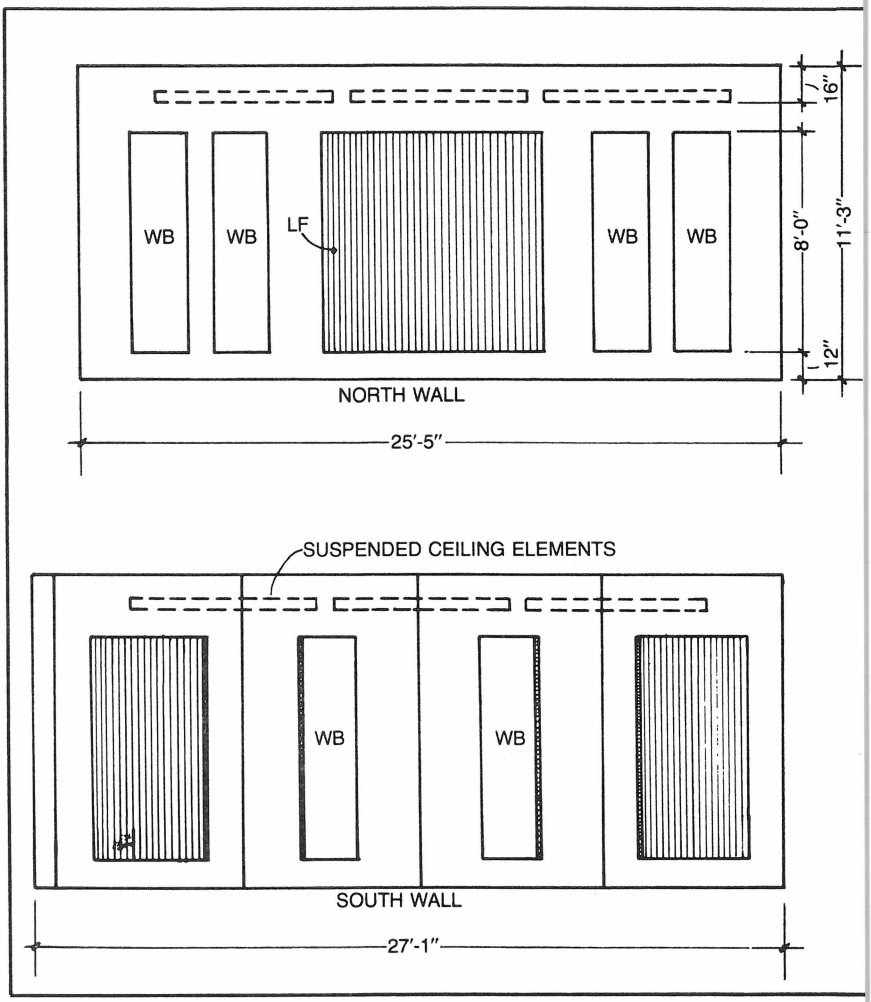
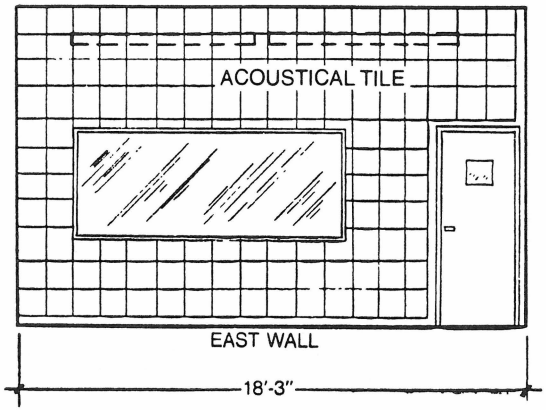
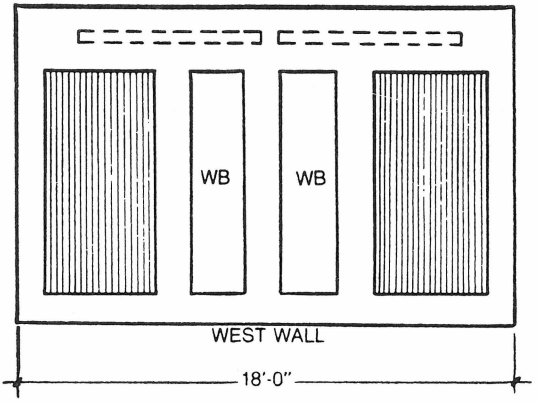


Fig. 8-8. Wall elevations of studio showing distribution and placement of wideband (WB) panels, low frequency (LF) absorbers and acoustical tile.

Wideband Modules

The wideband modules, described in Fig. 8-9, are similar to others in previous chapters. For example, these modules are similar to those of basically 4 inches of 703 type of glass fiber with a suitable mounting structure. Instead of a fabric face cover, a board is used. An ideal cover is Owens-Corning glass cloth covered Fiberglas boards 1 inch thick.





In some foreign countries such a board may not be readily available in which case a soft wood fiber board ½ inch thick could be substituted with modest degradation of absorption. Similarly, glass wool or glass fiber of other types could be substituted for the 703 Fiberglas if density approaches 3 pounds per cubic foot.

A degree of variation of studio acoustics can be introduced by mounting the eight wideband modules as shown in Fig. 8-10. Such a mounting allows reversal of each module by the simple expedient of flipping the top latch, lifting the module

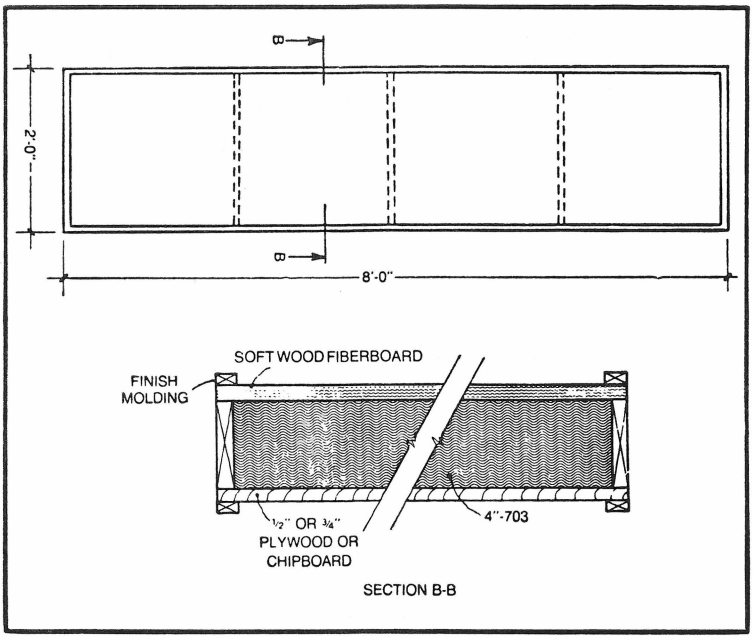


Fig. 8-9. Details of construction of the wideband wall modules having both a soft and hard face. These are mounted so that they may be reversed to adjust acoustics of the studio.

off the pin, reversing the module, replacing it on the pin and re-engaging the top latch. In this way either soft or hard faces of some or all of the modules could be exposed.

Low Frequency Absorbers

Figure 8-8 shows four 4 foot × 8 foot and one 8 foot × 8 foot low frequency absorbers on the studio walls. These can be built with either perforated facings or slat-slit facings, the latter being chosen in this particular design.

The frames of 2 × 8 lumber are first constructed and then the cross pieces of 2 × 8 are added as shown in Fig. 8-11A. At this point the frames are mounted on the wall with suitable angles and expansion screws (Fig. 8-11B). The crack between the frame and wall is then sealed on the inside with running beads of non-hardening acoustical sealant type of mastic so that each smaller section is essentially air tight as far as the wall junction is concerned.

The glass fiber material will probably be stiff enough so that, cut slightly large, the pieces will be held by friction

against the backs of the slats without support. If support is needed, zig-zag wires tacked to the 2 × 8s will assure close contact of glass fiber and slats. To avoid stroboscopic optical illusions as eyes are swept horizontally across the vertical slats, the face of the glass fiber should be covered with light weight black cloth. Instead of relatively light colored 703, Owens-Corning and perhaps other manufacturers, also make

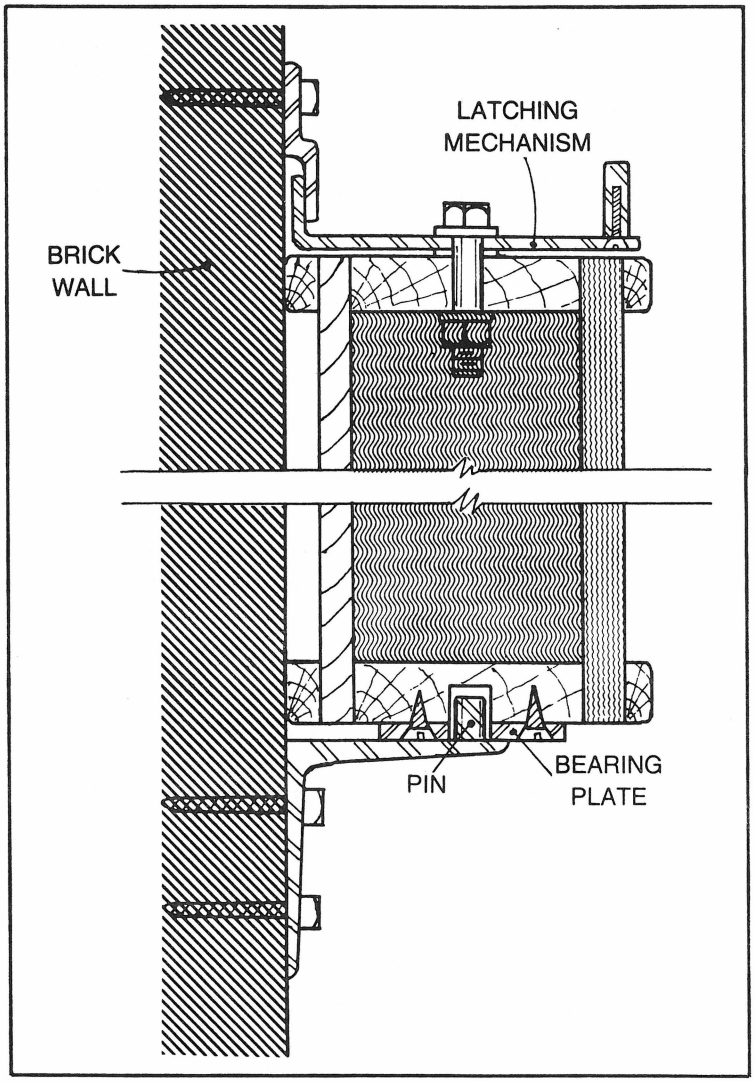


Fig. 8-10. Hardware for wideband wall modules to allow reversal.

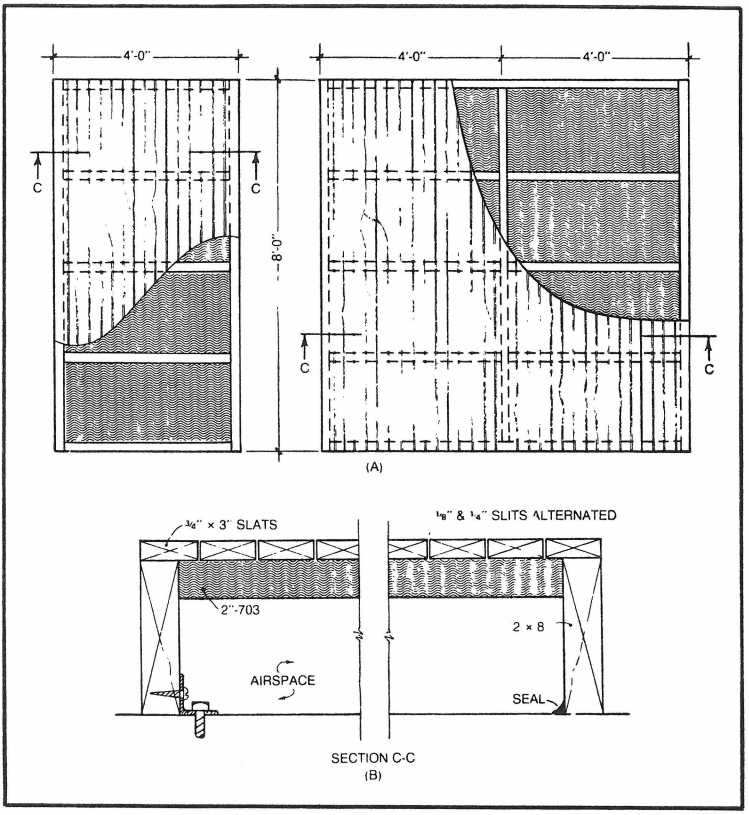


Fig. 8-11. Constructional details of slat type of Helmholtz low frequency resonators.

a black duct liner which has been used in this service. This would eliminate the need for the black cloth. The slats should be stained and varnished before nailing in place. The spacings should be alternately ⅛ inch and ¼ inch. The use of temporary shims while nailing assures uniform slits from top to bottom.

Acoustical Tile

The entire east wall (with the exception of the observation window and door) is to be covered with ½ inch acoustical tile (Fig. 8-8). These tiles may have perforations or slits or neither if of high quality. They are cemented in place in the usual way. The lower tiles are subjected to considerable abrasion and storing a few dozen matching tiles for later repairs is a good idea.

STUDIO CEILING

The studio ceiling has plaster 1 inch thick like the walls. To reduce the reflectivity of the ceiling, six elements are suspended by wires so that the lower edge of the 2 × 6 frames is 16 inches below the plaster surface. These elements hold absorbing material and light fixtures.

Figure 8-12A shows how the 6 foot–6 inch × 6 foot–6 inch frame of 2 × 6 lumber is subdivided into nine smaller sections. The center one holds a specially fabricated sheet

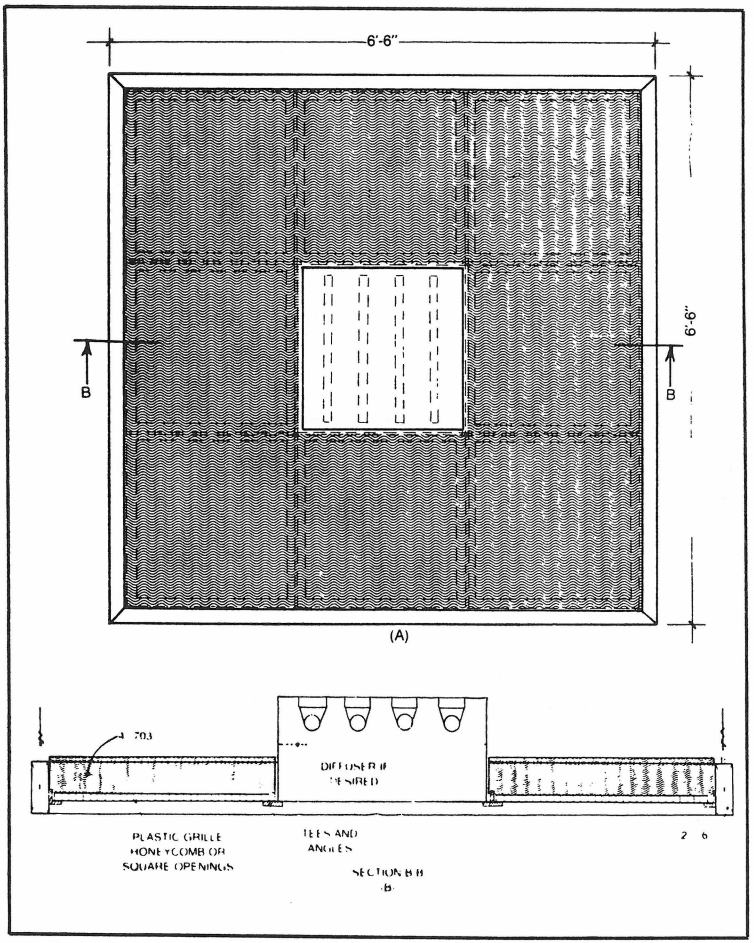


Fig. 8-12. Details of one of the six suspended ceiling frames in studio which hold the illumination fixtures and wideband glass fiber absorbers. Both faces of the glass fiber are active when so mounted.

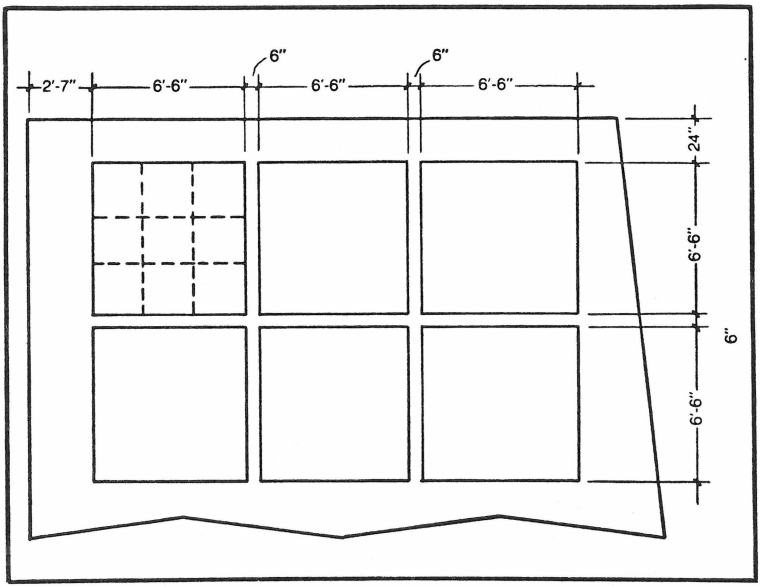


Fig. 8-13. Placement details of the six suspended frames in the studio.

metal rectangular box containing four 18 inch fluorescent tubes (remember that the starter reactors should be mounted outside the studio to avoid buzzing noises).

The inside lower edges of this metal box should be painted flat black. The deep recessing of the tubes and the black paint are to remove the tubes and their bright reflections from the view of those in the control room to avoid glare in the eyes and in the observation window.

Section B-B of Fig. 8-12B reveals the basic constructional features of each element. Metal *Ts and angles,* such as used in conventional lay-in suspended ceilings, form the 24 inch × 24 inch sections, eight of which have plastic grilles with honeycomb or square openings resting in them. The 4 inches of 703 is held up by these grilles. It is suggested that a light weight fabric be placed between the grille and the 703 it supports to prevent small bits of glass fiber from sifting down the artists' necks. Of the 48 24 inch × 24 inch sections, only 38 will be used to hold glass fiber in the design to follow. This means that there will be one or two vacant sections in each element. The vacant sections should be distributed randomly within the element and across the studio.

The six ceiling elements are suspended by wires from the ceiling joists according to the projected ceiling plan of Fig. 8-13.

CONTROL ROOM TREATMENT

The control room floor is also wood parquet. Opposing it is a conventional lay-in suspended ceiling dropped down 16 inches from the plastered surface. The walls are treated as shown in Fig. 8-14 with the same type of low frequency absorber used in the studio. They are constructed as shown in Fig. 8-11 and use the same acoustical tile.

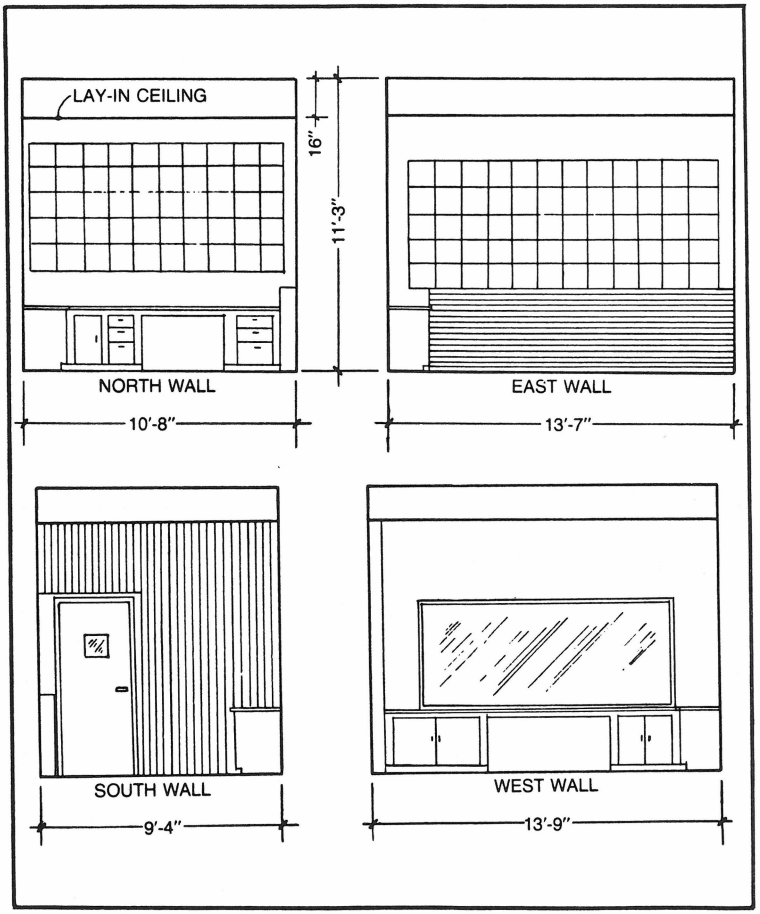


Fig. 8-14. Control room wall elevations showing distribution of slat resonators and acoustical tile. A conventional suspended ceiling is used in the control room.

Table 8-1. Studio Reverberation Time Calculations

SIZE.....25'-5" × 18'-3" × 27'-1" × 27'-1" × 18'-0" (two walls splayed)
FLOOR.....Wood parquet
CEILING.....Plastered with 6 suspended elements
WALLS.....8 wideband, 5 low frequency modules, acoustical tile
SURFACE AREA.....1,919 sq. ft.
VOLUME.....5,160 cu. ft.

MATERIAL	S Area sq. ft.	125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Floor: parquet	238	0.04	9.5	0.04	9.5	0.07	16.7	0.06	14.3	0.06	14.3	0.07	16.7
Floor: rug 10'×12'	120	0.05	6.0	0.10	12.0	0.15	18.0	0.30	36.0	0.50	60.0	0.55	66.0
LF units	160	0.98	156.8	0.72	115.2	0.33	52.8	0.21	33.6	0.16	25.6	0.14	22.4
Acous. Tile ½"	137	0.10	13.7	0.25	34.3	0.65	89.1	0.73	100.0	0.73	100.0	0.68	93.8
Ceiling elements:													
Lower surface	152	0.99	150.5	0.99	150.5	0.99	150.5	0.99	150.5	0.99	150.5	0.99	150.5
Upper surface	152	0.20	30.4	0.20	30.4	0.20	30.4	0.20	30.4	0.20	30.4	0.20	30.4
Total sabins, Sa without wall modules			366.9		351.9		357.5		364.8		380.8		379.8
Condition A													
Wall modules, soft side out 128		0.88	112.6	0.99	126.7	0.99	126.7	0.99	126.7	0.99	126.7	0.96	122.9
Total sabins, Sa			479.5		478.6		484.2		491.5		507.5		502.7
Ave. Absorp. Coeff., a			0.250		0.249		0.252		0.256		0.264		0.262
Reverb. Time, sec			0.46		0.46		0.45		0.45		0.43		0.43
Condition B													
Wall modules, hard side out 128		0.28	35.8	0.22	28.2	0.17	21.8	0.09	11.5	0.10	12.8	0.11	14.1
Total sabins, Sa			402.7		380.1		379.3		376.3		393.6		393.9
Ave. Absorp. coeff., a			0.210		0.198		0.198		0.196		0.205		0.205
Reverb. Time, sec.			0.56		0.60		0.60		0.60		0.57		0.57

STUDIO COMPUTATIONS

The generally accepted "optimum" reverberation time for a studio of 5160 cubic feet volume is about 0.67 second for music and 0.4 second for speech. The studio is to be used for both, hence some compromise reverberation time must be used. This could be warped upward or downward, depending upon whether music or speech were to be favored. The treatment of this studio has been presented as a *fait accompli* in previous paragraphs, but retracting the calculation steps should be a profitable exercise as this will provide the basis for the reader who wants to adapt this information to his own studio situation.

Table 8-1 gives reverberation time calculations for two conditions. Condition A is when the soft fiber board sides of all eight wideband modules are facing the studio. Condition B is when the hard faces of all eight wideband modules are exposed. The results of these calculations are presented in graphical form in Fig. 8-15.

The reverberation time can be increased about 30 percent by flipping the eight wideband wall modules from soft to hard side out. Although this must be determined by many listening tests, the best average condition would appear to be Condition A with wall modules soft. This would be essentially a speech condition shifted somewhat in the music direction.

The idea of reversing wall modules for every recording session is too idealistic and just too much work. The type of recording carried out in any studio invariably falls into one, two or a few categories and usually a single reverberatory condition meets the needs of most of the jobs. It is nice, however, to know that if especially bright conditions are desired for a certain type of music recording, the facilities are available to

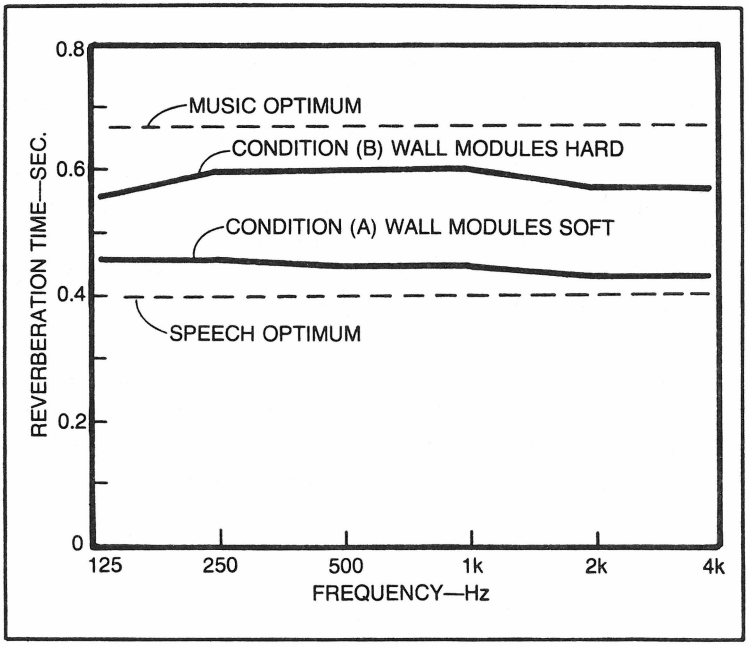


Fig. 8-15. Degree of reverberation time change made possible with reversible wideband wall modules.

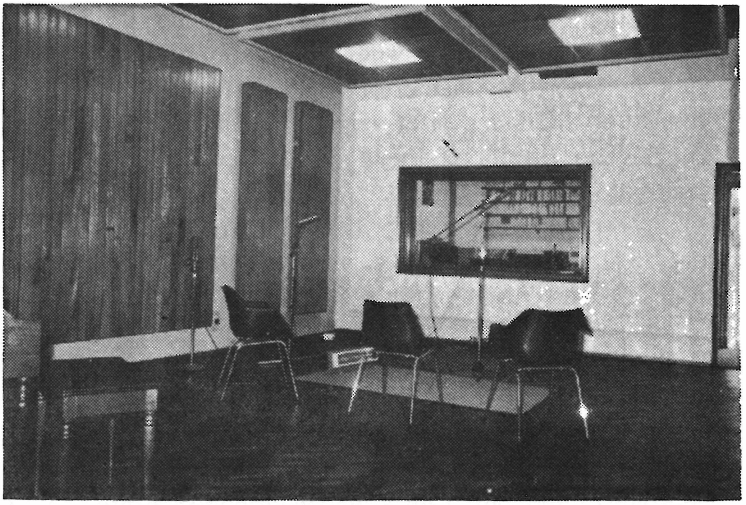


Fig. 8-16. The completed studio looking toward the observation window. (Centro Bautista De Communicaciones, Montevideo, Uruguay.)

attain these conditions. The diffusion of sound in the studio will certainly be better with soft wall modules than with hard modules. Good diffusion is especially needed for recording of speech.

Even greater flexibility in adjusting studio acoustics is available if the 24 inch × 24 inch pads of 703 in the six ceiling elements are involved. The design represented by Table 8-1 and Fig. 8-15 includes 152 square feet, or only 38 of the 48 possible absorbent sections in the ceiling frames. This would allow adding 10 sections or 40 sabins, or removing 10 sections with only minor sound diffusion effects if a distributed pattern of sections remaining is maintained.

Table 8-1 takes advantage of the fact that the ceiling element pads of 703 are capable of absorbing sound on both the lower and upper faces. As the upper face is somewhat shielded by the framework, an estimated 20 percent absorption is applied to the top surface. Acoustical measurements in the studio could very well demonstrate that the upper surface absorbs more than this.

CONTROL ROOM REVERBERATION

The reverberation time goal for the control room is about 0.3 second which is suitably shorter than the studio it serves.

Table 8-2. Control Room Reverberation Time Calculations.

SIZE ..... 13'-9" × 13'-7" × 10'-8" × 9' -4" (one wall splayed)
FLOOR ..... Wood parquet
CEILING ..... Lay-in Celotex Safetone Celotone, nat. fissured, ¾"
Mounting #7
WALLS ..... Slat type LF absorbers and Simpson Pyrotect
Micro Drilled Petite acoustical tile ¾" thick
SURFACE AREA ..... 804 sq. ft.
VOLUME ..... 1,530 cu. ft.

MATERIAL	S Area sq. ft.	125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Floor: parquet	108	0.04	4.3	0.04	4.3	0.07	7.6	0.06	6.5	0.06	6.5	0.07	7.6
Cabinets-½" plywood	90	0.30	27.0	0.23	20.7	0 18	16.2	0 14	12.6	0.11	9 9	0 10	9.0
Lay-in ceiling	136	0.50	68.0	0.54	73.4	0.55	74.8	0.77	104 7	0.87	118.3	0.88	119.7
LF slat absorbers	128	0.98	125.4	0.72	92.2	0.33	42 2	0.21	26.9	0.16	20.5	0 14	17 9
Acoustical tile	110	0.06	6.6	0.27	29.7	0.81	89.1	0.91	100.1	0.68	50 8	0.48	52.8
Total sabins, Sa			231.3		220.3		229.9		250.8		206.0		207.0
Ave. absorp. coeff., a			0.288		0.274		0.286		0.312		0.256		0.257
Reverb. time, sec.			0.27		0.29		0.28		0.25		0.32		0.31

Fig. 8-17. The studio wall opposite the window. (Centro Bautista De Communicaciones, Montevideo, Uruguay.)

The treatment shown in Fig. 8-14 approaches this as the computations of Table 8-2 reveal. Note that the low frequency absorption of the cabinets is a significant contribution. Although specific proprietary materials are listed for both the

Fig. 8-18. The completed control room. (Centro Bautista De Communicaciones, Montevideo, Uruguay.)

lay-in ceiling boards and the acoustical tile, there are many other products of the same type that would serve just as well if their different absorption coefficients are known and areas properly adjusted.

Figures 8-16, 8-17 and 8-18 are three views of completed studio and control room (Centro Bautista De Comunicaciones, Montevideo, Uruguay).

Chapter 9
Studios For a Commercial Radio Station

Feature: Measurements for trimming acoustics, perils of small studios.

The client in this example was represented by a very knowledgeable engineer who had already layed out a floor plan suitable for their needs. He wanted it checked out for room resonance distribution, a complete acoustical treatment plan for each room and then measurements to verify the design.

The floor plan already decided upon, shown in Fig. 9-1, includes master control, production control and a talk booth. That word *booth* infers that it is small and so it is. This one is 805 cubic feet, only half the minimum volume recommended. The other two rooms are somewhat larger than the minimum 1,500 cubic feet, 2,000 and 1,943 cubic feet.

In an operation such as this there is generally a great reluctance to be generous in the area devoted to recording, editing/listening and live broadcasting. After all, abstract and intangible acoustics are locked in a battle with down to earth factors such as space for offices for the station manager, production manager and engineer, as well as space for library, traffic and continuity, accounting, cafeteria, news and farm department, announcers' work area and last and most important, ample room for *SALES*.

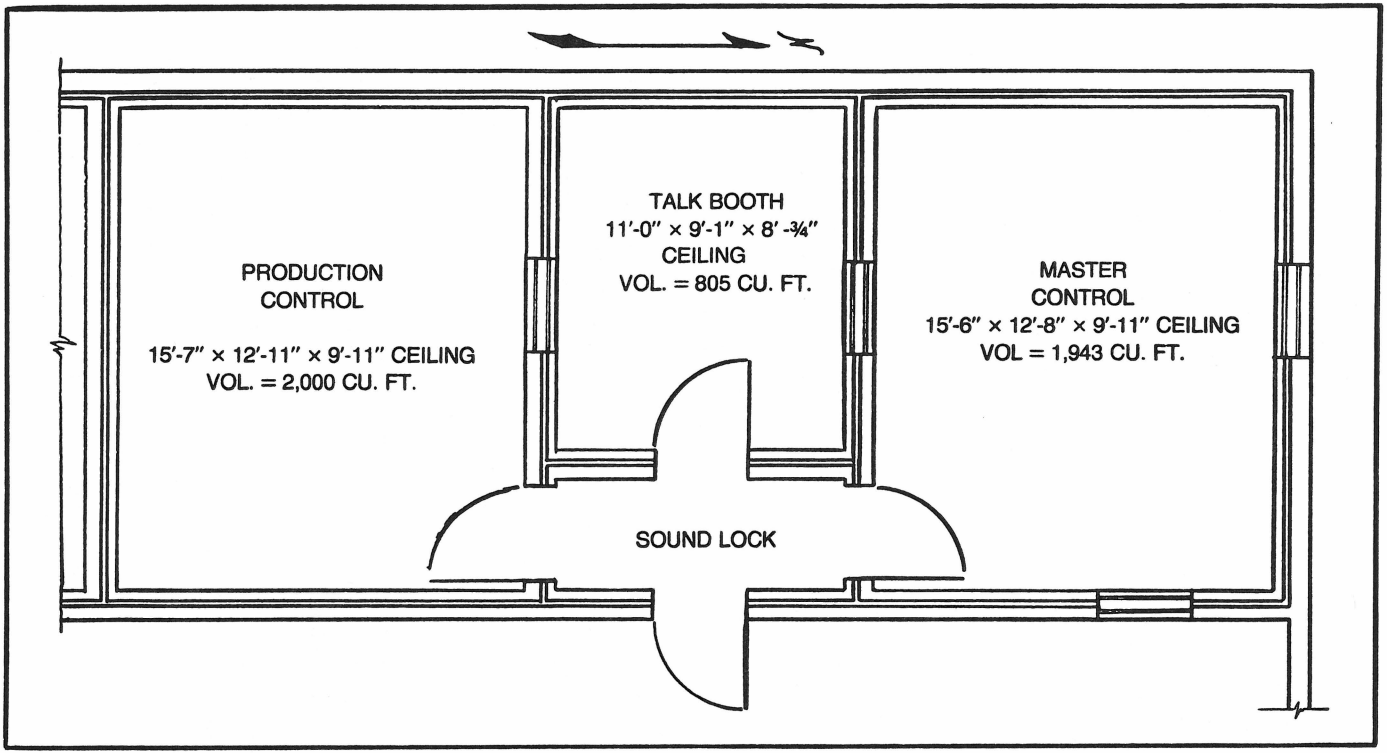


Fig. 9-1. Floor plan for highly efficient studio and work space for a commercial radio station. The talk booth is substandard in size.

To keep the studio area under control there are pessimists around who would even question straining for acoustical quality when the audio signal is routinely highly processed to get the effect of greater transmitter power. The signal might not be so good, but signal coverage and resulting sales apparently are best served by such a procedure. Another argument tending to scuttle support for acoustical quality of broadcast studios is that little goes out live anymore except voice, and the announcer always close-talks the microphone. It is true that room effects are most noticeable for greater source to microphone distances but the imprint of the room is always there, no matter how close the microphone to the source.

CONSTRUCTION

The studio area of Fig. 9-1 is one corner of a 55 foot × 60 foot single story structure. The walls of the studio area are of 6 inch concrete block, an air space of 2 inches and an inner wall of 4 inch concrete block as shown in Fig. 9-2. The hollow spaces in the concrete blocks of both tiers were filled with concrete, well-rodded to eliminate air pockets. The external walls have added thermal protection because of the northern location.

The exterior face of the external walls is covered with stucco or siding. The 2 inch air space is filled with thermal type of glass fiber. The inner surface of the 4 inch block tier of external walls is covered with ⅝ inch gypsum board furred out on 2 × 2s with the space behind also filled with a thermal type of glass fiber.

The interior walls of the studio area are the same basic construction as the external walls as far as the 6 inch and 4 inch concrete block tiers and the 2 inch air space are concerned. The similarity ends there as the air spaces of the interior walls have no glass fiber in them nor is there a gypsum board layer. It was specified that the inner faces of all walls were to be painted.

An exterior window was insisted upon in the north wall of master control. Another window in the east wall allows other staff workers to see what is going on in master control without entering. The two windows in the talk booth are lined up so that personnel in the three rooms can see their colleagues in

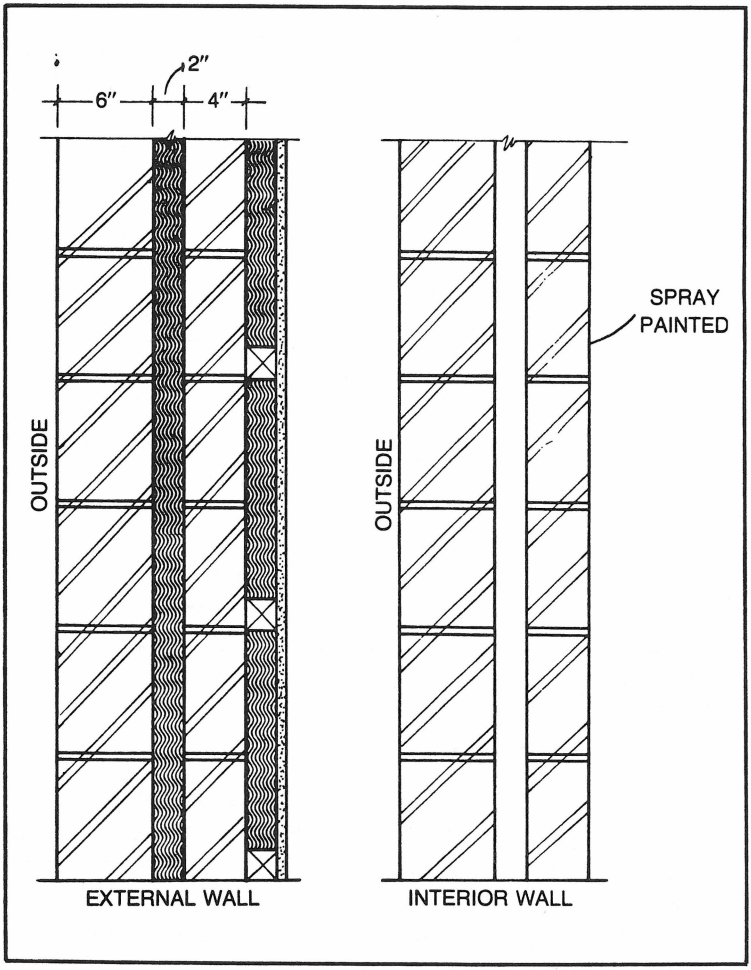


Fig. 9-2. Wall construction details for studio walls. As this studio is located in a northern area, the external walls are filled with glass fiber insulation between the two concrete block tiers and the inner face is covered with ⅝ inch gypsum board furred out 2 inches with insulation behind. The interior walls are of the same block construction but without the thermal treatment.

the other rooms. This allows the use of hand signals. In fact, someone in production control can look through both the talk booth and master control to the next range of mountains! The production value of this feature is not too evident unless it is to be able to say during a weather broadcast, "It's snowing hard here." From the acoustical standpoint lining up windows is very bad, especially if the glass plates are parallel.

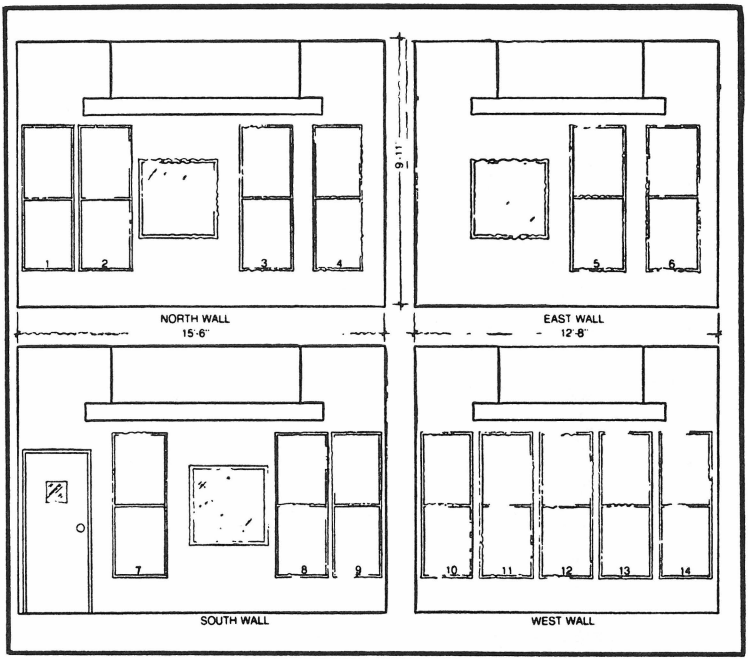


Fig. 9-3. Wall elevations of master control showing original location of wideband wall modules before adjustments were made.

ACOUSTICAL TREATMENT

In this chapter constructional details of wideband wall modules, suspended and other ceiling elements, etc., are to be passed over in favor of some new and, hopefully, more interesting features. The treatment of master control (Fig. 9-3), production control (Fig. 9-4) and the talk booth (Fig. 9-5) are quit similar to those of other earlier chapters with one simplifying factor: there are no carpet in these rooms. This means no low frequency resonators are required to compensate for the carpet. Presumably, all we need are areas of 4 inches of 703 suitably disposed around each studio to insure against flutter echo and to give the best sound diffusion. These areas are provided in three forms:

- wideband wall modules
- suspended ceiling elements in master and production control rooms
- an acoustically similar ceiling frame in the talk booth

GENERAL MEASUREMENTS

The three studios treated as shown in Figs. 9-3, 9-4 and 9-5 were subjected to acoustical measurements. Only the reverberation results will be discussed in this chapter. These measurements as well as the design were all accomplished by mail. The consultant did not visit the studio site. Working at a distance, the consultant sent a magnetic tape with test signals on it to the engineer who played them according to detailed instructions in each room, picking up each room's response to these signals on a suitable microphone placed as directed and recording the response on another tape recorder. Upon receiving the response tapes in the mail the consultant proceded to analyze them. In very general terms, reverberation time, swept sine tests and the room's response to impulses were recorded and analyzed.

REVERBERATION TIME

The goal for reverberation time was taken as a nominal 0.3 second, relatively uniform 125 Hz to 4 kHz. The average

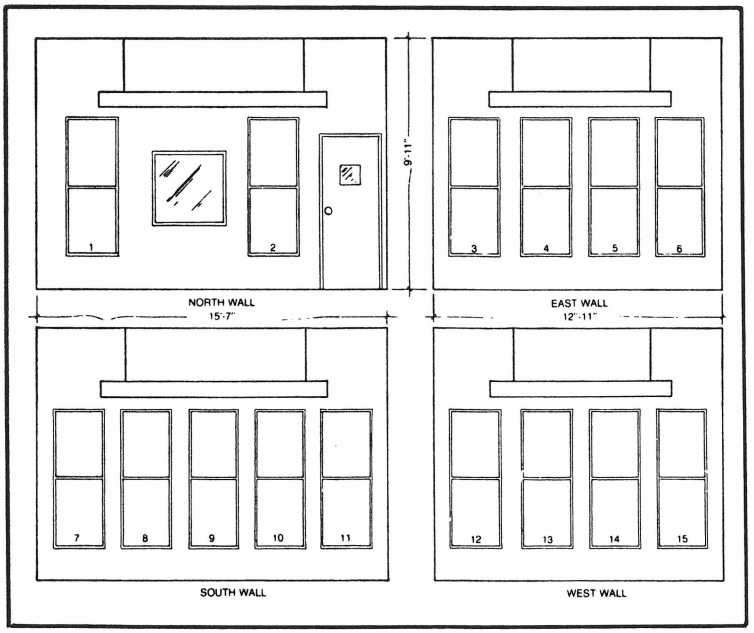


Fig. 9-4. Wall elevations of production control showing original location of wide-band wall modules before adjustments were made.

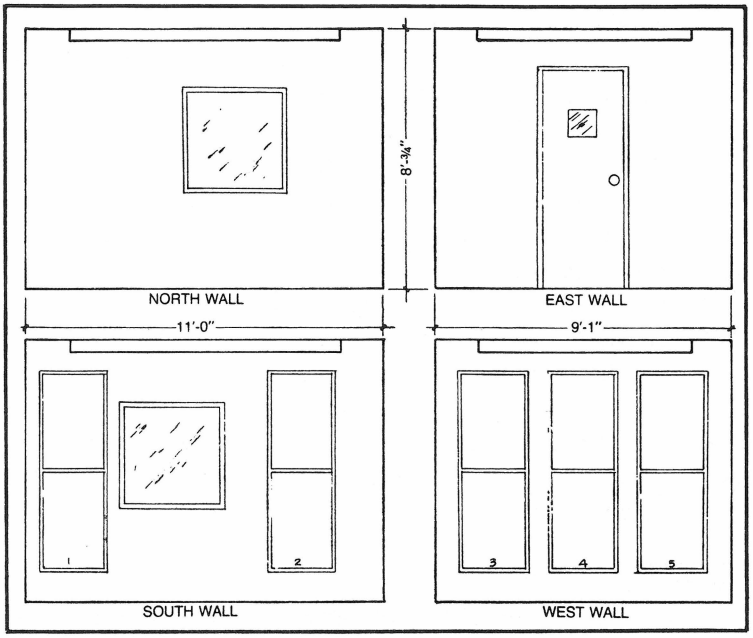


Fig. 9-5. Wall elevations of talk booth showing original location of wideband wall modules before adjustments were made.

measured reverberation time of the three studios is shown in Fig. 9-6. All three are substantially below 0.3 second. Well, you win some and you lose some! But the detective in each of us says, "Why?" If this business is not based on rational physical principles as we were led to believe by our physics teacher, perhaps the gnome in the cave up in the mountain might cease his peeping and muttering long enough to design studios for us. Not that the reverberation characteristics of Fig. 9-6 are all that bad. A studio having a reverberation time of 0.2 second is quite usable, but its sound would be, stated subjectively, dry, dead and outdoorish in character. The difference between the 0.3 second goal and 0.2 second reality, however, is a distinct challenge and a problem worth solving.

THEORY VS. PRACTICE

The consultant and the radio engineer exchanged views and information by letter, telephone and one visit of the engineer with the consultant. A number of examples of questionable communication accuracy were disclosed:

- Knowlege of the furred out gypsum board on the inside of exterior walls came after the basic design was completed.
- The block surfaces were to be painted. It was learned that they were spray painted. The idea of the original painting specification was to close the tiny surface pores of the coarse concrete blocks which absorb the sound, but the kind of paint to use was not stated clearly by the consultant. The spray paint evidently was non-bridging in nature, serving only to stabilize the surface somewhat and to give color, but not to seal off the interstices.
- The third factor was the uncertainty as to how effective the top surface of the 4 inches of 703 in the suspended ceiling would be in absorbing sound. In other words, how well is it shielded from sounds of various frequencies filling the room? The manufacturer's coefficients are not given for such double-sided exposure for this type of product because only one side is normally exposed. In the original design the consultant assumed that the top surface of the 703 would absorb about half as well as the lower surface. We shall see that this is too conservative.

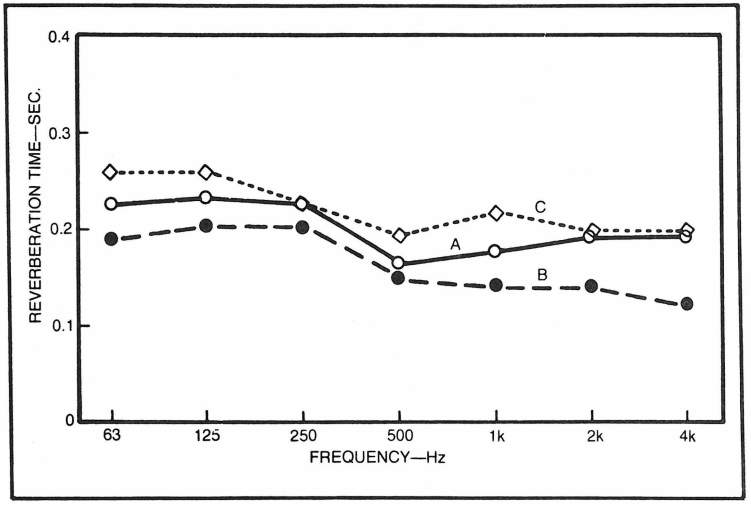


Fig. 9-6. Measured reverberation time of the three studios; (A) master control, (B) production control and (C) talk booth.

- Owens-Corning gives the absorption coefficient of 4 inch thick 703 as 0.99 for frequencies from 125 Hz to 4 kHz.[33] The following discussion will suggest that, under the present circumstances, 0.99 may be a bit optimistic for 125 Hz and 250 Hz.

The calculations leading to the original design gave essentially 0.3 second reverberation time 125 Hz-4 kHz for each of the three studios of Fig. 9-1. But these original calculations did not include the uncertainties introduced later which are listed in the previous paragraph.

The problem now is how to account for the measured reverberation time graphs shown in Fig. 9-6. Our confidence in the whole procedure hinges on our ability to account for the actual reverberation time prevailing in these rooms. Accordingly, a series of cut and try approximations were made in which the absorption coefficients differ in the following ways from those of the original calculations which predicted about 0.3 second reverberation time in each room:

(1) The coefficients for 4 inches of 703 were reduced to 0.85 for 125 Hz and 0.90 for 250 Hz. For 500 Hz-4 kHz the 0.99 value supplied by Owens-Corning was used.[33]

(2) The area of the 703 used in the suspended ceiling frame was doubled rather than increased by 50 percent. This assumes that the top face is just as effective as the lower face in absorbing sound.

(3) The absorption coefficients for concrete block walls were taken from an obsolete source[34] as seen in Table 9-2. The original design, assuming that the paint filled the surface pores, utilized the coefficients in the right hand column. Learning that the walls were spray painted, it was judged that the coefficients of the left hand column applied more closely. It is interesting that the above listing for coarse concrete block walls, unpainted, did not appear in the next issue of the same source,[35] apparently in recognition of the highly variable nature of the surfaces of concrete blocks made by different firms. Part of the cut and try calculations showed

Table 9-1. Master Control Calculations

SIZE..... 15'-6" × 12'-8", 9'-11" ceiling
FLOOR..... Vinyl tile on concrete
CEILING..... Double ⅝" gypsum board on wood joists.
Suspended 1×6 frame holding 4" of 703 glass fiber
WALLS..... Concrete block exterior walls covered with
⅝" gypsum board furred out on 2×2s, space
filled with thermal glass fiber (Fig. 9-2).
Interior concrete bock, coarse, spray painted
(Fig. 9-2). Wideband modules, 2'×6', 4" 703 (Fig. 9-3)
SURFACE AREA..... 951 sq. ft.
VOLUME..... 1,943 cu. ft.

MATERIAL	S Area sq. ft.	125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Ceiling, 4" 703 69 sq. ft., both sides active	138	0.85	117.3	0.90	124.2	0.99	136.6	0.99	136.6	0.99	136.6	0.99	136.6
N&W walls ⅝" gyp board, 2" fill	162*	0.15	24.3	0.14	22.7	0.12	19.4	0.10	16.2	0.08	13.0	0.05	8 1
E&S walls coarse concrete block	183*	0.10	18.3	0.15	27.5	0.31	56.7	0.29	53 1	0.39	71.4	0.25	45.8
Ceiling: dbl ⅝" gypsum board	196	0.08	15.7	0.05	9.8	0.03	5.9	0.03	5.9	0.03	5.9	0 03	5 9
Wideband wall modules (14)	168	0.85	142.8	0.90	151.2	0.99	166.3	0.99	166.3	0.99	166.3	0.99	166.3
Total sabins, Sa		318.4		335.4		384.9		378.1		393 2		362.7	
Ave. Absorp. Coeff., a		0.335		0.353		0.405		0.398		0.414		0 381	
Reverb. Time, sec.		0.25		0.23		0.19		0.20		0 19		0.21	

*Corrected for wideband module area

Table 9-2. Concrete Block Absorption Coefficients

Frequency Hz	Coarse, Unpainted	Painted (Bridging paint)
125	0.36	0.10
250	0.44	0.05
500	0.31	0.06
1k	0.29	0.07
2k	0.39	0.09
4k	0.25	0.08
	Source: Ref. 35	

clearly that the concrete block surfaces, spray painted, did not absorb as well as indicated in Table 9-2 for 125 Hz and 250 Hz and these coefficients were reduced to 0.1 and 0.15, respectively. However, those for 500 Hz and above were retained.

(4) The areas of concrete block were reduced by the exterior wall area covered with furred out gypsum board. Master control has two such walls and the other rooms each have one.

(5) The absorption of the wideband wall modules was decreased at 125 Hz and 250 Hz as for the suspended ceiling elements discussed in (1).

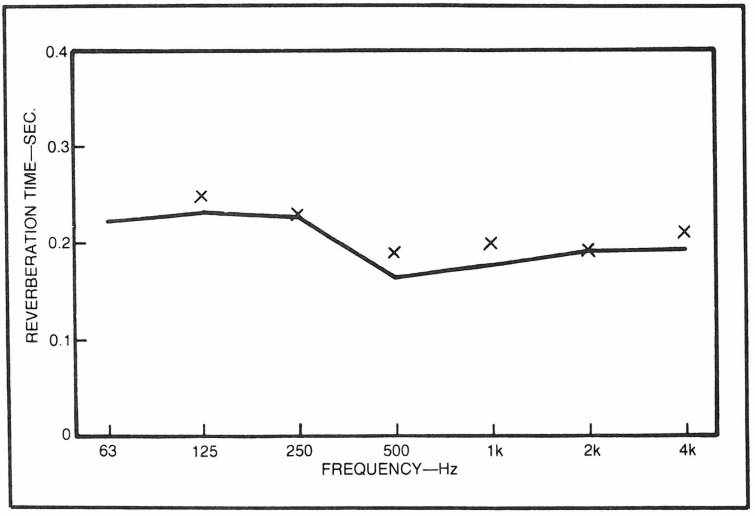


Fig. 9-7. Measured reverberation time in master control repeated from Fig. 9-6 (solid line). The calculated points (x) using refined data are in close agreement.

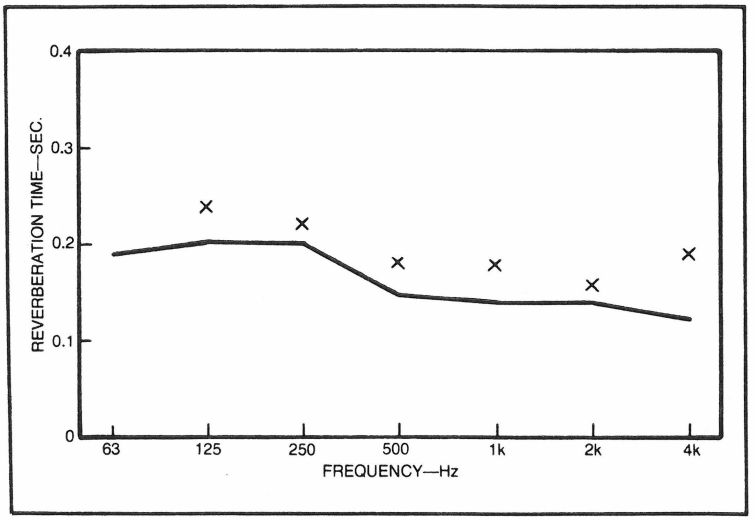


Fig. 9-8. Measured reverberation time in production control repeated from Fig. 9-6 (solid line). The calculated points (x) using refined data show somewhat poorer agreement that Fig. 9-7.

To make a long story short, the recalculated reverberation time for master control, taking into account the factors listed in (1) to (5), are listed at the foot of Table 9-1. These calculated points agree quite well with the measured values as shown in Fig. 9-7.

Reverberation time was recalculated for production control using the identical coefficients and the results are displayed in Fig. 9-8. Here the calculated values are consistently high, but reasonably close. The recalculated values of reverberation time for the talk booth, using the same coefficients, are plotted in Fig. 9-9. The measured and recalculated values of

Table 9-3. Values of Reverberation Time

	Reverberation Time, Seconds		
	Measured	Recalculated	
Master Control	0.198	0.212	+7%
Production Control	0.160	0.195	+22%
Talk Booth	0.222	0.207	−7%

reverberation time, averaged for six frequencies, are compared in Table 9-3.

These are not perfect, but they do reflect the type of problems encountered in predicting studio performance. Figures 9-7, 9-8 and 9-9 show far superior agreement between measured and calculated values, however, than a comparison of the three graphs of Fig. 9-6 with the 0.3 second goal closely approached in the original design.

Recapitulating, the coefficients of Table 9-1, with their estimated changes from the book, yield far better agreement with measured values than those without the changes.

There are a number of lessons here. First, there is no substitute for actual measurements. Second, published values of absorption coefficients determined in reverberation chambers may or may not predict performance accurately in practical situations. A third lesson is that acoustical treatment applied in modules allows easy trimming. As an example, now that the coefficients have been adjusted to give reasonable agreement with the measured values, we may be confident in using them to adjust the reverberation time upward to approach the goal of 0.3 second more closely. This can now be done with greater confidence and accuracy than the original design which, for several reasons, did not come too close to the 0.3 second goal (Fig. 9-6).

MASTER CONTROL TRIMMING

To increase the reverberation time of master control from graph A in Fig. 9-6 to approximately 0.3 second across the band, the following must be done:

- The 69 square feet of 4 inches of 703 in the suspended ceiling frame is reduced to 50 square feet (100 square feet counting both top and bottom surfaces).
- The number of wideband modules on the walls is reduced from 14 to 8. These 8 must be carefully deployed so that bare wall surfaces parallel to each other do not, as far as possible, face each other. Modules #1, 3, 5, 8, 11 and 13 of Fig. 9-3 are removed and the remaining ones positioned with

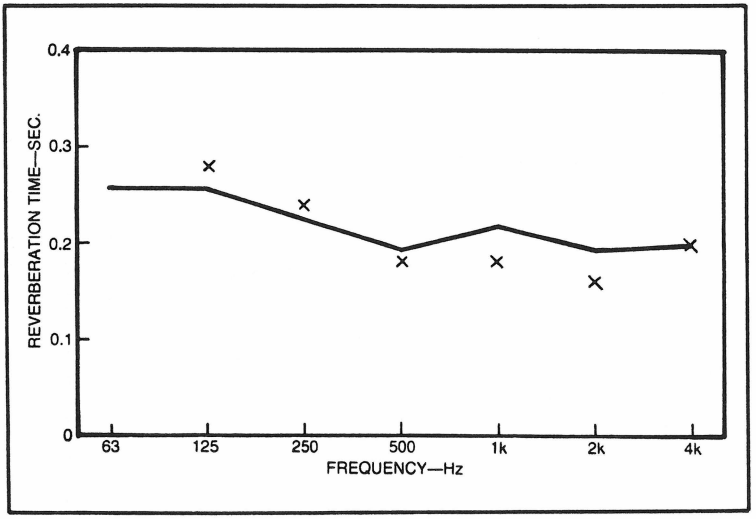


Fig. 9-9. Measured reverberation time in talk booth repeated from Fig. 9-6 (solid line). The calculated points (x) using refined data show reasonably good agreement.

proper attention to what they face on the opposite wall.

PRODUCTION CONTROL TRIMMING

To increase the reverberation time of production control from graph B in Fig. 9-6 to approximately the 0.3 second goal, the following reduction in absorbing surfaces are made:

- The 69 square feet of 4 inches of 703 in the suspended ceiling frame is reduced to 25 square feet (50 square feet counting both sides).
- Six wideband wall modules (#4, 6, 7, 11, 12 and 14 of Fig. 9-4) are removed, reducing the total from 15 to 9. These nine must also be positioned to reduce standing waves between opposite walls.

TALK BOOTH TRIMMING

The small size of the talk booth creates a problem in that the minimum area of absorbing surfaces required to control standing waves results in a reverberation time less than 0.3 second. As this cannot be helped, the following changes are in order:

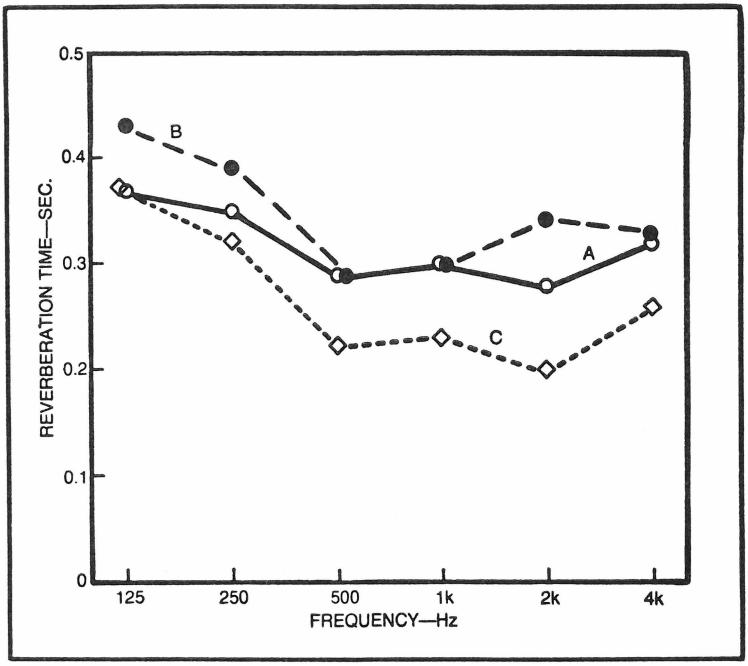


Fig. 9-10. The expected reverberation time characteristic of the three rooms after recommended trimming has been accomplished. The bass rise shown results from assumed reduction of 4 inch 703 absorption coefficients at 125 Hz and 250 Hz. The existence of this bass rise must be checked by further measurements (A) master control, (B) production control and (C) talk booth.

- The ceiling frame in the talk booth, fastened directly to the ceiling, has 24 inch × 24 inch sections in a 4 × 3 array giving a total of 12 sections. Pads of 4 inch 703 are to be removed from half of them, the remaining six to be distributed wisely, considering the operator's position and general diffusion of sound.
- Only a single wideband wall module can be removed from the west wall or standing wave conditions will be degraded seriously.

SUMMARY

The expected reverberation time characteristics of the three rooms resulting from the above changes are shown in Fig. 9-10. From 500 Hz up, the master control and production control rooms are not too far from the 0.3 second goal. The

talk booth, over the same frequency range, levels off nearer 0.22 second, an inferior result stemming from the substandard size of the room.

All three have distinct increases in reverberation time at bass frequencies. This is a natural result of decreasing the absorption coefficients of 4 inch 703 at 125 Hz and 250 Hz (Table 9-1) to get calculations to agree with measurements.

The big question now is whether the bass rise really exists or whether it is an artifact. The logical approach would be to repeat the measurements and settle the question once and for all. The BBC experience[10] referred to in Chapter 4 showed that an increase of 20 percent of the 125 Hz reverberation time over that at 500 Hz is allowable for voice. Master control bass rise comes to 27 percent, production control 48 percent, and talk booth 37 percent.

If measurements confirm the existence of this much bass rise of reverberation time, some low frequency resonators must, of course, be introduced to pull it down. A very rough estimate would indicate that using a resonator tuned to 125 Hz and assuming 100 percent absorption at this peak (i.e., one sabin per square foot of resonator), the following areas would

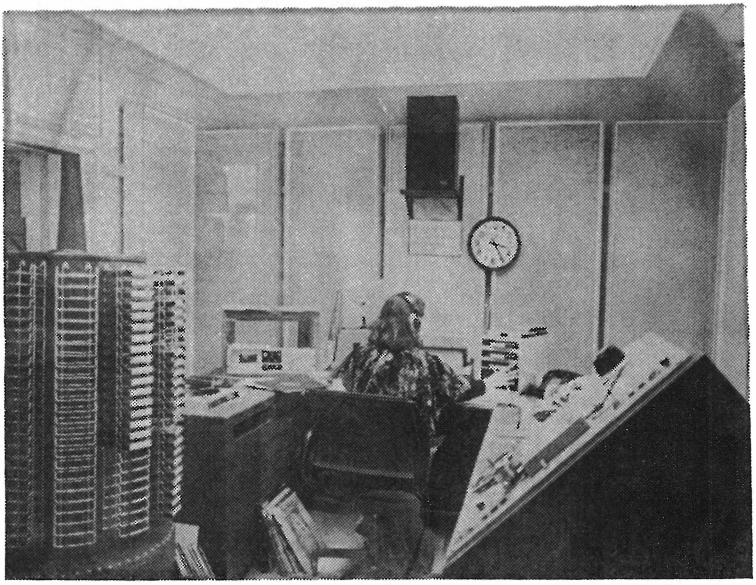


Fig. 9-11. The master control room of commercial radio studio complex (Golden West Broadcasting, Ltd., CHRB, High River, Alberta, Canada).

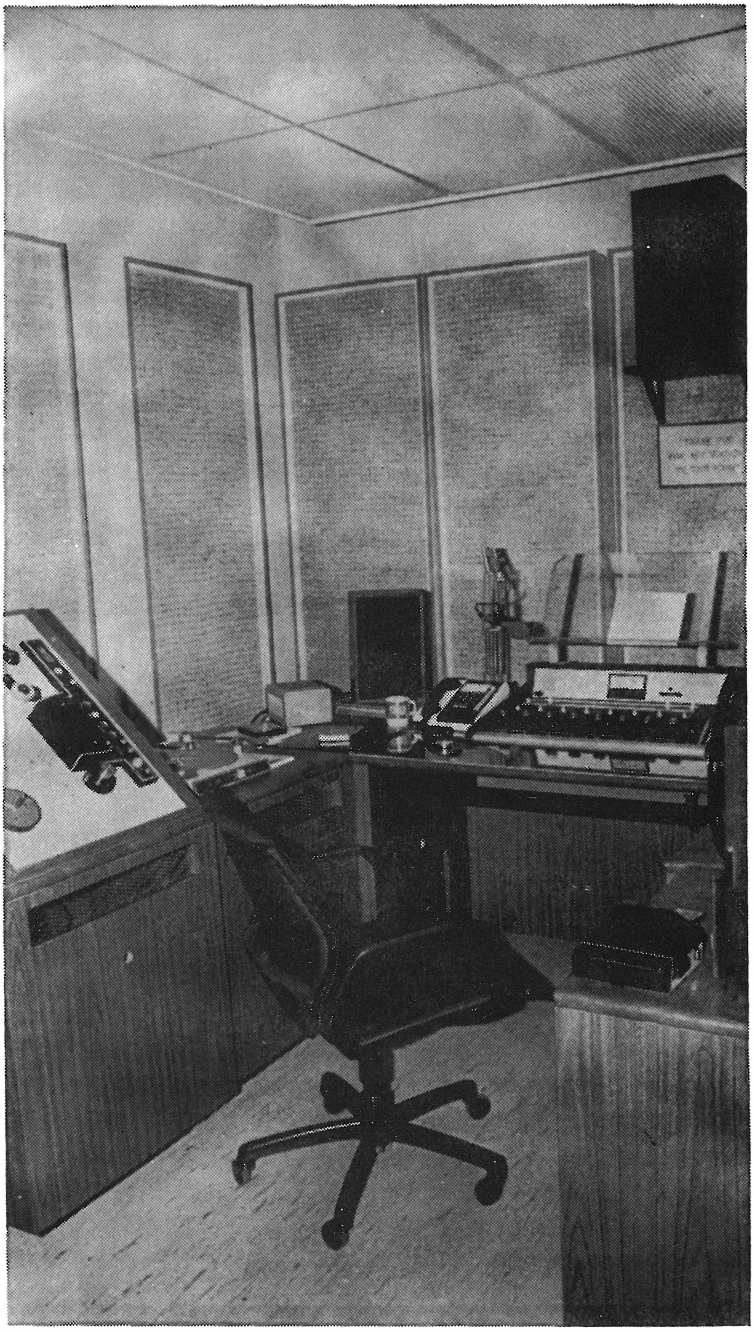


Fig. 9-12. The production control room of commercial radio studio complex (Golden West Broadcasting, Ltd., CHRB, High River, Alberta, Canada).

Fig. 9-13. The talk booth of commercial radio studio complex (Golden West Broadcasting, Ltd., CHRB, High River, Alberta, Canada).

be required: master control, 51 square feet; production control, 83 square feet; and talk booth, 53 square feet.

Figures 9-11, 9-12 and 9-13 illustrate the completed commercial radio studio complex by showing views of master control, production control and the talk booth prior to trimming.

Chapter 10
One Control Room For Two Studios

Features: Small modules for treatment, use of cork, semicylindrical elements, room air conditioners.

Whether or not having only one control room to serve two studios is satisfactory depends upon the intensity of the recording schedule. If recording sessions are well spaced and the schedule is flexible, having only one control room might work very well. Certainly, the advantages of requiring only one console, one set of recording equipment and using only one operator are self-evident.

The problem arises when it is necessary to use both studios simultaneously. Even if duplication of equipment and the use of two operators were accepted as the price for a fuller recording schedule, the conflict of monitor loudspeakers becomes apparent. Which recording job gets the loudspeaker(s)? Which operator uses headphones?

For the activity that does not require such overlapped scheduling, however, the single control room for two studios can work out very well. And, as we have seen in Chapter 7, headphone monitoring is becoming an ever more viable alternative as headphone quality is undergoing rapid and dramatic improvement.[15]

The incentive for such improvement, it must be admitted, comes from the hi-fi market, not from recording engineers who still prefer loudspeakers. How much of this is inertia from the recent past when loudspeaker quality far outstripped headphone quality is difficult to say. The point here is that this is a new day and the quality difference is much less. Headphones might very well be used by one operator as he records speech from one studio while another operator records music from another using monitor loudspeaker(s). However, the loudspeaker level would have to be kept down.

STUDIO SUITE LAYOUT

The example to be considered is another of those cases in which the studio suite had to be fitted into space available in an existing building. After the usual battle for space, the pro-studio faction came up with the end of the third and top floor of a concrete building overlooking a quiet patio farthest from a busy thoroughfare. The overlooking part was immediately cancelled as all windows in the studio area were bricked up and plastered on both sides.

After the usual preliminary consultation period, the floor plan of Fig. 10-1 was agreed upon. The client was insistent upon one control room for two studios and was willing to go to headphones for a second operator if the recording load increased that much in the future.

The sound lock is a strangely shaped space, but for a good reason. The existing hall required an offset sound lock to reach the control room without robbing the music studio of too much area. The walls of the sound lock, if straight, would cut off corners in both studios with approximately 45 degree walls. Looking into these corners from either studio emphasized that such a straight wall across the corner tends toward a concave effect when considered along with the adjoining walls.

Acousticians always get worried when confronted with concave or quasi-concave surfaces, but nothing makes them happier than convex surfaces. So, why not make convex sound diffusing surfaces out of these sound lock walls and let the concave sides be in the sound lock where they can do no harm? Walls of brick are quite amenable to shaping in this fashion. In fact, leaving the rough brick texture aids diffusion

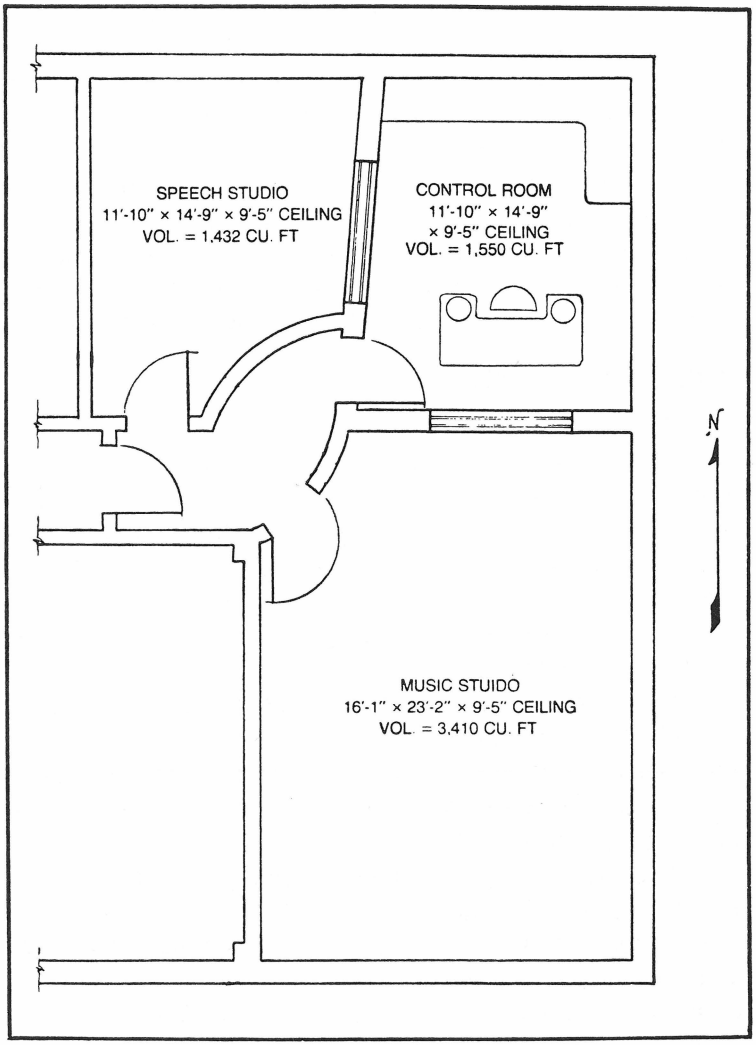


Fig. 10-1. Floor plan of recording suite in which both a speech studio and music studio are served by a single control room. This arrangement works best if the work load is modest and the schedule flexible. A second operator can handle one studio (e.g. the speech studio) by monitoring with high quality headphones).

just that much more and provides an attractive visual feature in each room.

The volumes of the control room (1,550 cubic feet) and the speech studio (1,432 cubic feet) are very close to the 1,500 cubic foot minimum, yet are adequate for their intended purposes. The music studio at 3,410 cubic feet provides

reasonably adequate space for the largest music group contemplated.

ACOUSTICAL TREATMENT

The acoustical treatment of the three rooms is strongly based on a modular plan. There are three types of modules of 24 inch × 24 inch outside dimensions. Each has a different absorption characteristic:

- A wideband (WB) module which absorbs equally well over the frequency range 125 Hz-4 kHz.
- A low peak (LP) module having a peak absorption at about 125 Hz.

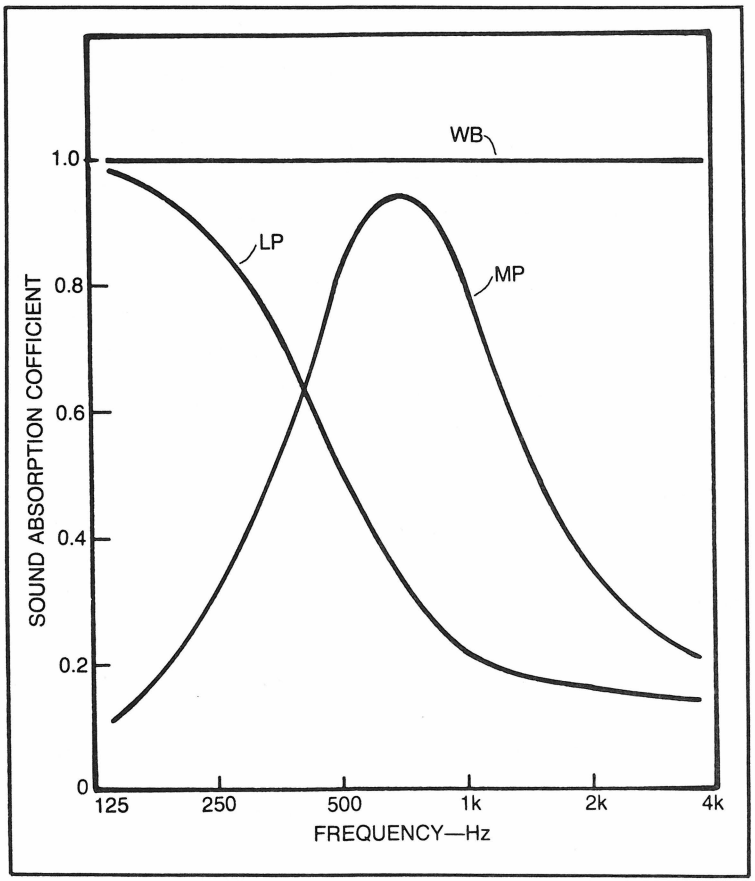


Fig. 10-2. Comparison of absorption vs. frequency characteristics of wideband (WB), low peak (LP) and mid peak (MP) types of sound absorbers.

- A mid peak (MP) module which peaks at about 800 Hz.

The absorption of these three modules is contrasted in Fig. 10-2. These are three basic building blocks capable of compensating for the absorption of carpets, drapes, acoustical tile or other materials having unbalanced absorption and performing other tasks in the acoustical treatment of a room. As there is no reason to be limited to these three, versatile as they are, other materials such as cork and convex panels will be used.

MUSIC STUDIO TREATMENT

The wall treatment of the music studio is shown in Fig. 10-3, the floor and ceiling treatment in Fig. 10-4.

The north wall leaves little space for acoustical elements because of the observation window and the convex brick wall in the northwest corner. The east and south walls are practically covered with 24 inch × 24 inch modules of two types, low peak and wideband. The west wall is dominated by three large and three smaller convex panels.

The ceiling (Fig. 10-4) has 96 cork tiles 12 inches × 12 inches × 1 inch cemented to it in an irregular pattern built up of groups of four cork tiles. It was not possible to attain the desired reverberation time if the floor was covered with carpet wall to wall as requested, hence a compromise of an 8 foot × 10 foot rug is specified. Each absorptive element will be discussed individually in connection with the music studio, although the same elements are used in other rooms as well.

Ceiling Treatment

The cork tiles of 12 inches × 12 inches × 1 inch were selected because they were readily available in this particular foreign country and are considered very attractive by some people. Absorption coefficients for cork may be difficult to locate. As it was a popular acoustical material 50 years ago before the acoustical industry sprouted, coefficients can be found in old textbooks.

Inspecting these coefficients (Table 10-1), low absorption at low frequencies and better absorption at higher fre-

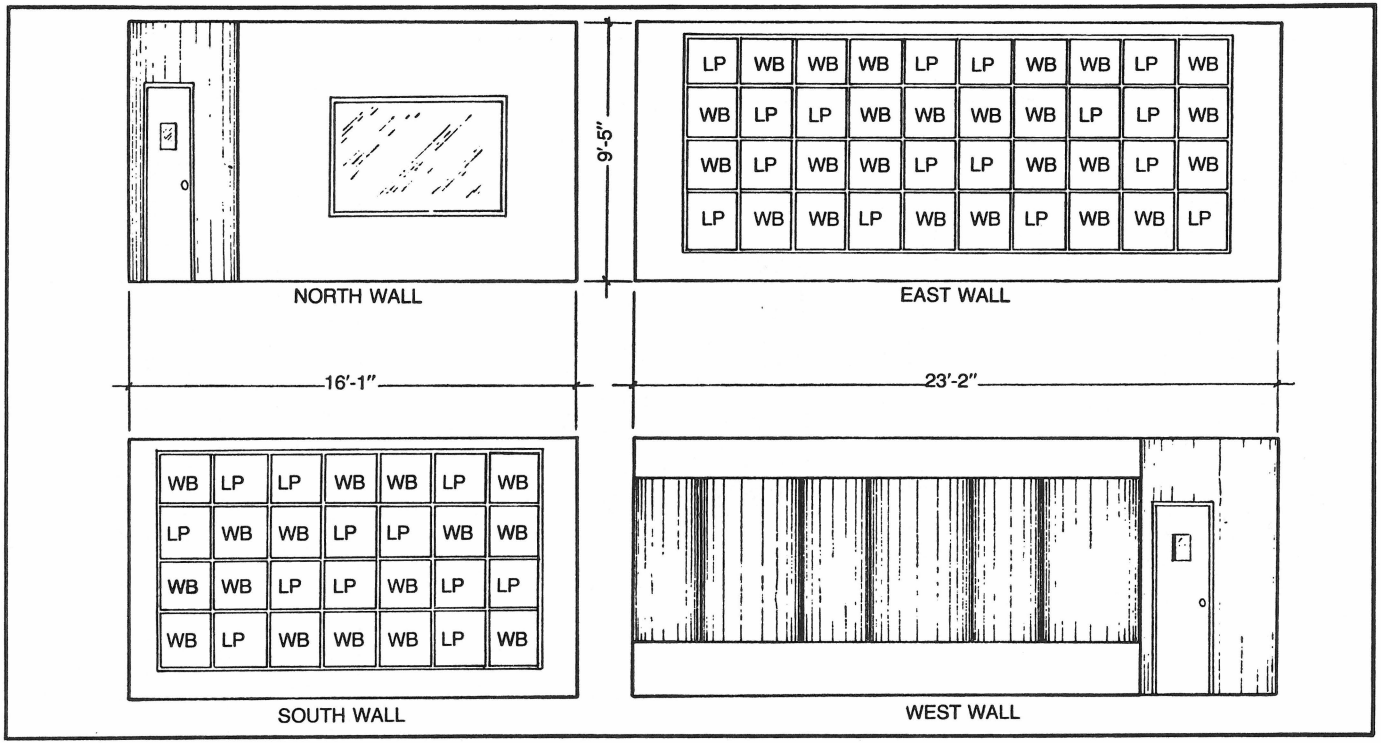


Fig. 10-3. Wall elevations of music studio. The door is set in a semicylindrical brick sound lock wall. Plywood polycylindrical diffuser/absorbers cover the west wall and wideband (WB) and low peak (LP) modules cover the east and south walls.

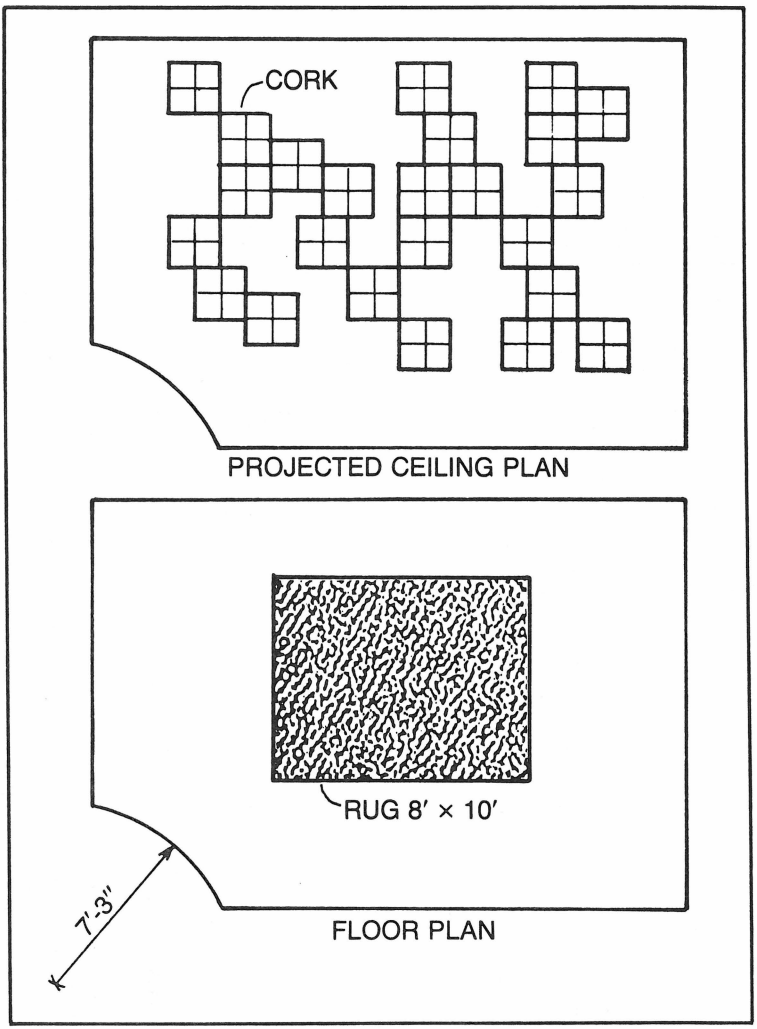


Fig. 10-4. Projected ceiling and floor plan of music studio. Cork tiles 1 inch thick are arranged in a pattern on the ceiling and an 8 foot×10 foot rug is placed anywhere on the floor dictated by microphone placement.

quencies are noted. The absorption varies much the same as the rug on the floor and about the same order of magnitude. If cork is to be replaced by acoustical tile, it should be the thinnest and cheapest tile available because ¾ inch modern acoustical tile is a far more efficient absorber than 1 inch cork.

Actually, it would be preferred to have a compensating type of absorber on the ceiling opposite the rug, but there is

Table 10-1. Music Studio Calculations.

SIZE .....16'-1" × 23'-2", ceiling 9'-5"
FLOOR .....Wood parquet, 8' × 10' rug
CEILING .....96 cork tiles 12" × 12" × 1" random pattern
WALLS.....40 wideband, 28 low peak modules, convex panels
SURFACE AREA.....1,439 sq. ft.
VOLUME.....3,410 cu. ft.

MATERIAL	S Area sq. ft.	125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Floor: 8' × 10' rug	80	0 05	4 0	0 10	8 0	0 15	12.0	0 30	24.0	0.50	40.0	0.55	44.0
Floor: wood parquet	282	0 04	11.3	0 04	11.3	0 07	19 7	0.06	16.9	0.06	16.9	0.07	19.7
Cork tiles 12" × 12" × 1"	96	0.05	4 8	0 10	9.6	0.20	19.2	0 55	52.8	0.60	57 6	0.55	52.8
Walls: low peak													
28 @ 3.62 sq. ft.	101	0 98	99.0	0.88	88 9	0 52	52.5	0 21	21.2	0 16	16.2	0.14	14.1
Walls: wideband													
(40)	145	0 99	143.6	0 99	143 6	0.99	143.6	0 99	143.6	0 99	143.6	0.99	143.6
Convex panels:													
3 large, empty	66	0.41	27 1	0.40	26.4	0 33	21.8	0 25	16.5	0.20	13.2	0.22	14.5
Convex panels:													
3 small, empty	44	0 32	14 1	0.35	15.4	0.30	13.2	0.25	11.0	0.20	8.8	0.23	10.1
Total sabins, Sa			303.9		303.2		282.0		286.0		296.3		298.8
Ave. Absorp. Coeff., a			0.211		0.211		0.196		0.199		0.206		0.208
Reverb. Time, sec.			0.49		0.49		0.53		0.52		0.50		0.50

the potential problem of not knowing just where the rug will be in the studio and mounting compensating (LP) modules on the wall is easier than on the ceiling.

Wall Treatment

The modules on the east and south walls are constructed according to the plan of Fig. 10-5. The wideband (WB) module is simply a frame holding 4 inches of 703 (or two layers of 2 inches) or similar glass fiber boards of about 3 pounds per cubic foot density.

This glass fiber is held in place by zig-zag wires at the appropriate level creating an air space of approximately 1¼ inches. This air space helps to extend good absorption to lower frequencies, or, looking at it another way, it helps us come closer to realizing in practice the 0.99 coefficient at 125 Hz and 250 Hz supplied by the manufacturer.

The face of the 703 is held in place by a light weight expanded metal lath appropriately spray painted before installation. It may be advisable to cover the 703 with a stretched light weight fabric before the expanded metal is applied. The backs of both of these modules are uncritical, ¼ inch hardboard or plywood is adequate.

The LP module having an absorption peak at about 125 Hz is housed in a frame identical to that of the wideband absorber. Only 2 inches of 703 is required in this case and the facing is 3/16 inch hardboard or plywood drilled with 3/16 inch diameter holes spaced 1 9/16 inches center to center. By stacking the panels a number can be drilled simultaneously, reducing the tedium somewhat. A loosely woven fabric cover over this perforated cover for esthetic reasons is optional.

One of the weightier problems of treating these studios is how to mount the 24 inch × 24 inch modules on walls and ceilings. One of the advantages of the modular approach is to facilitate trimming room acoustics if measurements indicate the need.

Therefore, ideally, the best type of mounting is the one which allows easy removal or interchange of modules. This is best accomplished by building a frame into which the individual modules may be inserted or removed at will. A frame of this type is described in Fig. 10-6.

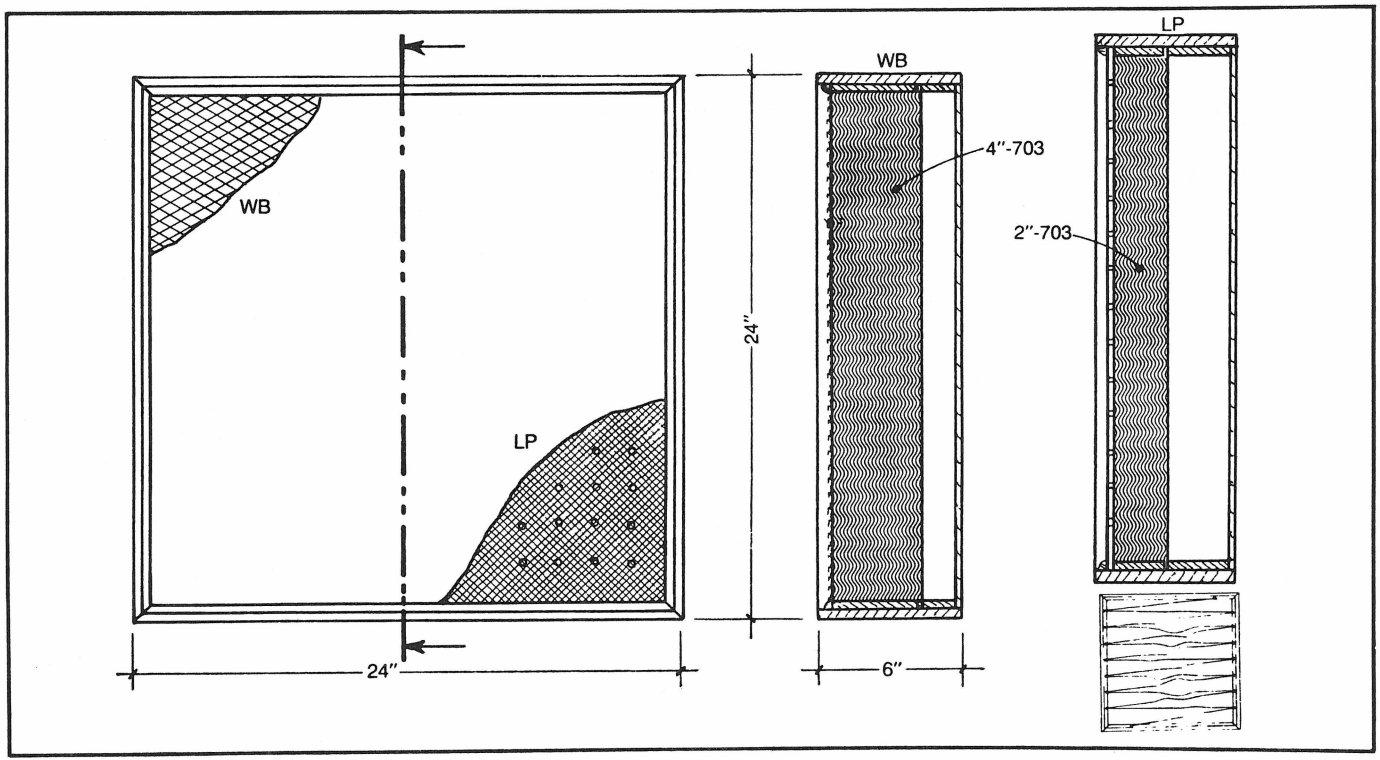


Fig. 10-5. Constructional details of wideband (WB) and low peak (LP) absorbing modules which are built in identical boxes.

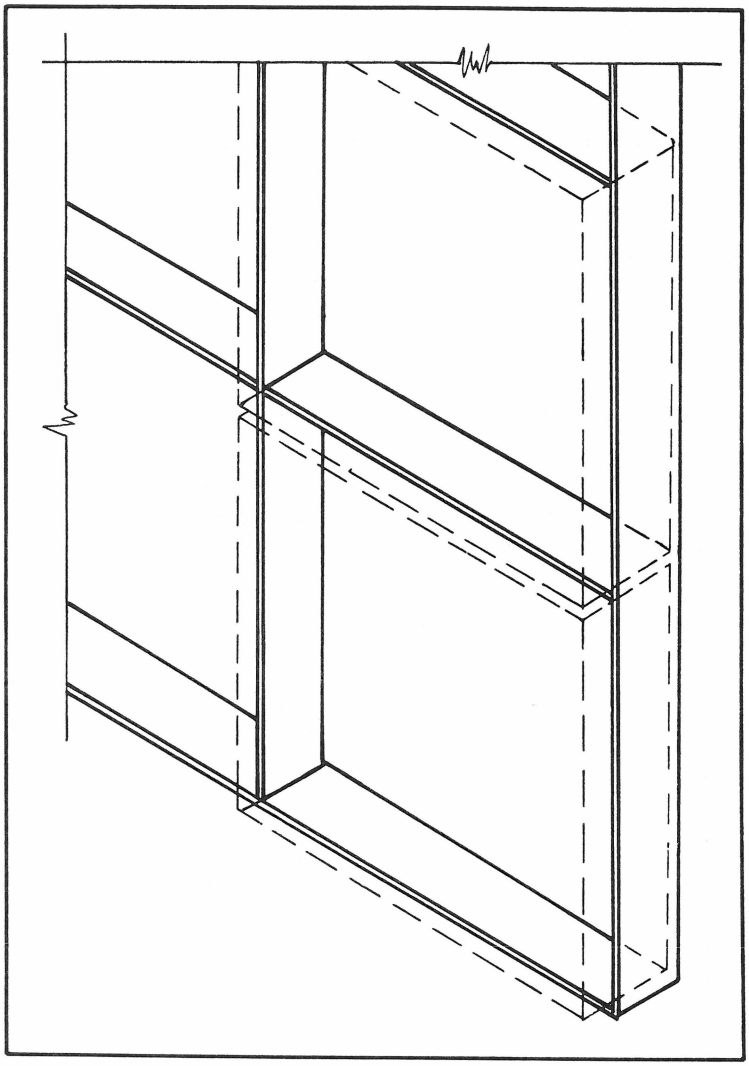


Fig. 10-6. Wideband (WB), low peak (LP) and mid peak (MP) absorbing modules can be conveniently slid in and out of a simple wall frame of 1 × 4 lumber.

Another less desirable approach is to affix the box itself firmly to the wall and to consider the contents interchangeable, but not the external box. If the contents were removed, a fabric face would preserve visual continuity, but its acoustical effect would be essentially removed.

On the other hand, a WB absorber could be changed to an LP by changing glass fiber depth and cover. Making a mid peak

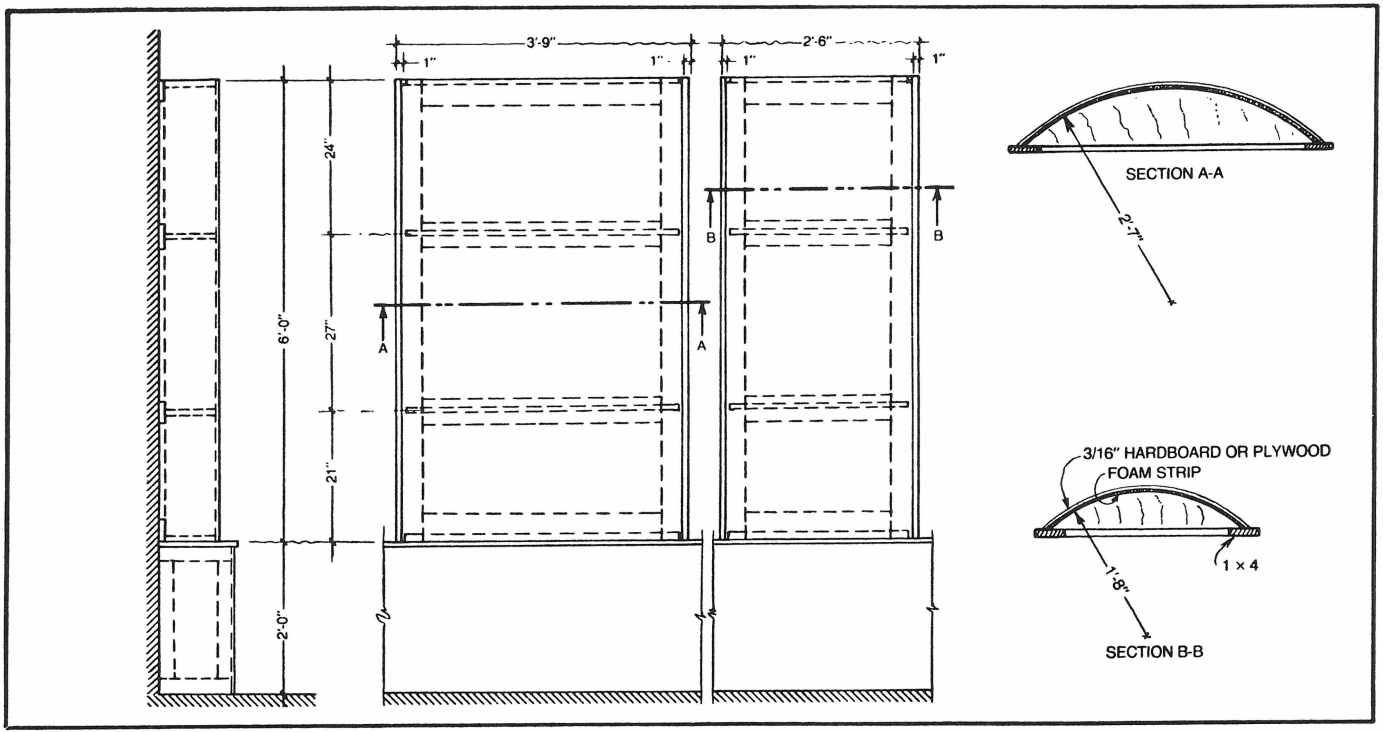


Fig. 10-7. Constructional details of polycylindrical diffusers/absorbers on west wall of music studio. They are fastened to the wall and rest on a simple base enclosed with plywood.

(MP) absorber, to be described later, out of a WB or LP would require using the bottom of the box, leaving some empty space behind the grille cloth cover, but it would serve its acoustical function satisfactorily. It is also possible to stack the boxes like cord wood on a low support, making the stack stable with well placed cleats or other ties.

Each WB and LP box weighs about 20 pounds. With the adhesives available today the boxes could be cemented directly to the wall. With the acoustical guidance in this and other chapters, it is not too much to expect the mounting problem to be solved, along with a host of other problems, by the ingenuity in residence.

West Wall Polys

The polycylindrical or convex acoustical elements on the west wall of Fig. 10-3 have two things going for them: bass absorption and excellent diffusing characteristics.[3] They require only modest skill in construction.

The details of Fig. 10-7 show a skin of 3/16 inch hardboard or plywood stretched over bulkheads previously cut on the arc of a circle with a bandsaw. The larger unit requires a sheet about 48 inches wide and the smaller one about 32 inches. No acoustical filling is required inside.

When music fills the room the vibration of the covering skin is easily felt by placing the fingers on it. It is important that rattles be prevented. This can best be done by placing a thin foam rubber strip with a self-adhesive backing along the edge of each bulkhead before nailing the skin. The bulkheads divide the space within each convex element into three unequal, essentially airtight, compartments. All three large and three small convex elements rest on a low, enclosed shelf. As this is covered with ½ inch plywood, it also is a fair bass absorber of the flat panel type. Because this 18 foot shelf contributes only 2.5 percent of the absorption of the room at the most, its effect is minor and is not included in Table 10-1.

With the treatment described the reverberation time of the music studio hovers around the desired 0.5 second as shown numerically in Table 10-1 and graphically in Fig. 10-8.

SPEECH STUDIO TREATMENT

A reverberation time of 0.3 second is the goal for the speech studio. Carpet was specified in this room. In fact, an indoor-outdoor type of carpet was specifically requested for economy. This is included wall-to-wall. Opposing the carpet, 27 low peak (LP) modules are mounted to the ceiling, arranged as shown in Fig. 10-9. The matter of attachment to the ceiling, admittedly somewhat more complicated than to the wall, is left to local ingenuity.

The treatment of the walls of the speech studio is shown in Fig. 10-10. The east and south walls are dominated by the convex masonry wall shared with the sound lock. The north and west walls each have 20 modules, most of them (27) are the wideband (WB) modules as used in the music studio. A third type of 24 inch × 24 inch module, the midpeak (MP), is used only in this studio.

Combining the absorption of the indoor-outdoor carpet with the low peak (LP) ceiling modules, a deficiency of absorption around 800 Hz results. One method of boosting this sagging midband absorption is to introduce 13 modules having

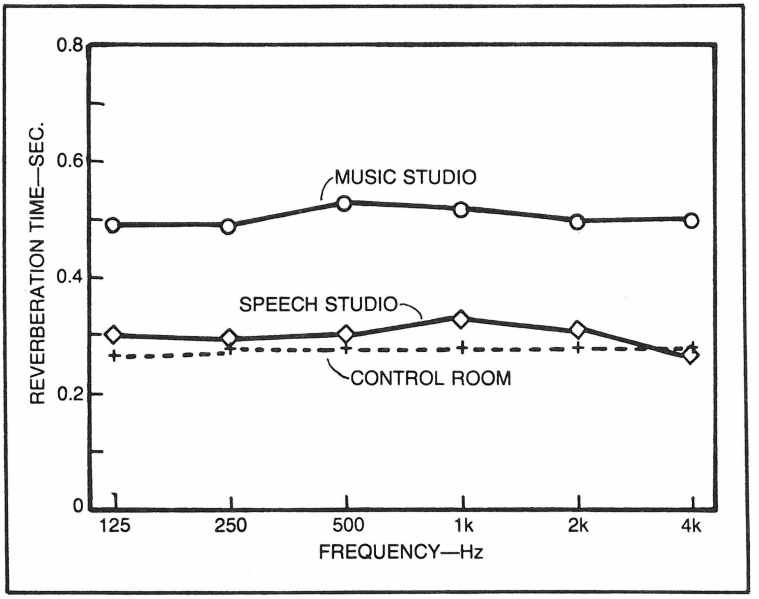


Fig. 10-8. Calculated reverberation time vs. frequency chracteristics of music and speech studios and control room.

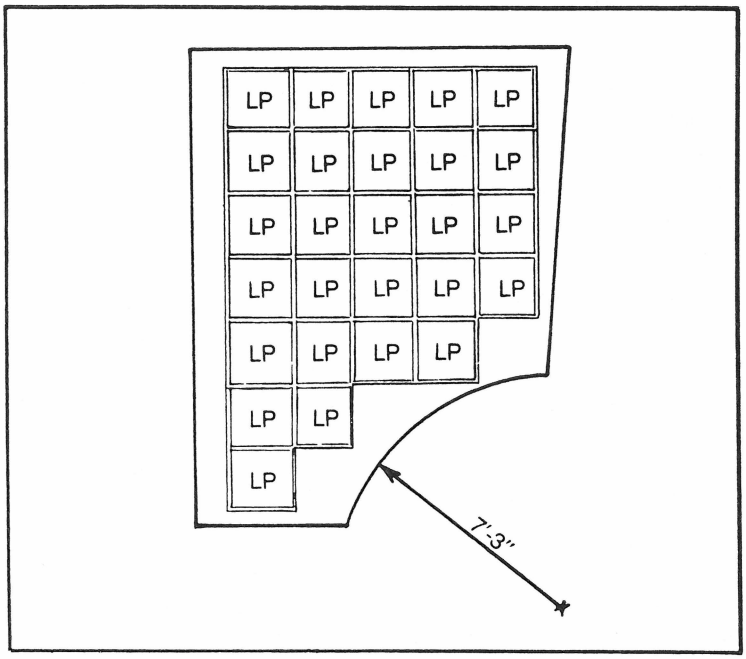


Fig. 10-9. Projected ceiling treatment plan for speech studio. The low peak (LP) absorber modules are the same as those used on the wall of the music studio.

peak absorption in this frequency region as shown in Fig. 10-2. The net result is a calculated 0.3 second reverberation time for the speech studio which is a quite uniform 125 Hz to 4 kHz as shown in Fig. 10-8. The computations and other details are found in Table 10-2.

The construction of the midband (MB) modules is detailed in Fig. 10-11. It is a very shallow module with a 1 inch cavity filled with 703 or other type of glass fiber material covered with a perforated panel. Like the low peak (LP) module, it is a tuned Helmholtz type of resonator. The resonance frequency is determined by such things as the percentage perforation (the percentage of the hole area to the entire cover area), the thickness of the panel, and the depth of the enclosed cavity.

The glass fiber broadens the absorption peak. The cover is common stock pegboard. Different types of pegboard have different hole configurations and hence different perforation percentages. The diamond hole configuration is square when

Table 10-2. Speech Studio Computations

SIZE ..... 11'-10" × 14'-9", east wall splayed

FLOOR ..... Indoor-Outdoor carpet wall to wall

CEILING ..... 27 low peak modules

WALLS ..... 27 wideband and 13 midband modules

SURFACE AREA ..... 768 sq. ft.

VOLUME ..... 1,432 cu. ft.

MATERIAL	S Area sq. ft.	125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Floor; indoor/ outdoor carpet	152	0.01	1.5	0.05	7.6	0.10	15.2	0.20	30.4	0.45	68.4	0.65	98.8
Ceiling: 27 low peak @ 3.62 sq. ft.	98	0.98	96.0	0.88	86.2	0.52	51.0	0.21	20.6	0.16	15.7	0.14	13.7
Walls: 27 wideband	95	0.99	97.0	0.99	97.0	0.99	97.0	0.99	97.0	0.99	97.0	0.99	97.0
Walls: 13 midband	47	0.09	4.2	0.30	14.1	0.80	37.6	0.80	37.6	0.35	16.5	0.20	9.4
Total sabins, Sa			198.7		204.9		200.8		185.6		197.6		218.9
Ave. Absorp. Coeff., a			0.259		0.267		0.261		0.242		0.257		0.285
Reverb. Time, sec.			0.30		0.29		0.30		0.33		0.31		0.27

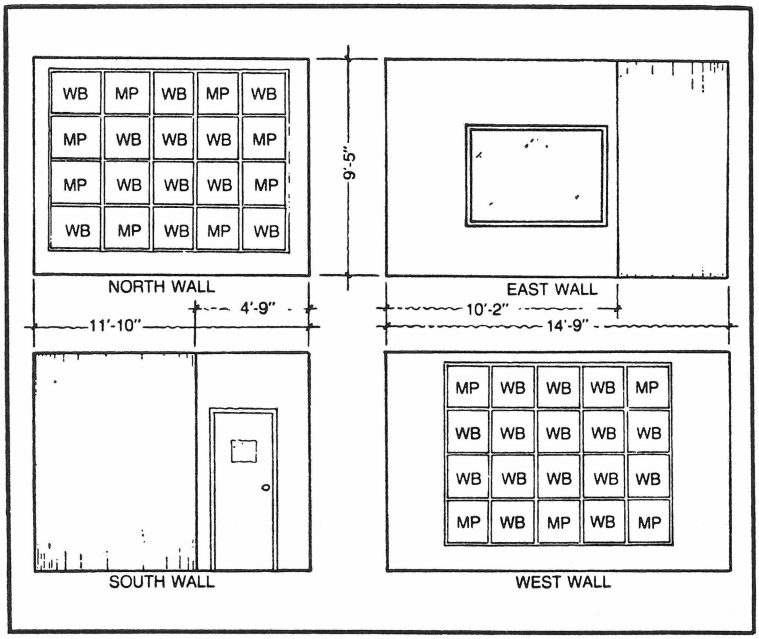


Fig. 10-10. Wall elevations of speech studio showing placement of wideband (WB) and mid peak (MP) absorber modules.

the panel is rotated 45 degrees. A common diamond type of pegboard comes with 5/32 inch holes spaced ¾ inches center to center on the square.

The perforation percentage of this type is about 3.4 percent. A perforation percentage between 3 and 6 percent is required. Figure 10-11 includes a sketch showing how the perforation percentage for the entire cover of any type of pegboard can be readily calculated on a unit basis knowing only hole diameter and spacing.

CONTROL ROOM TREATMENT

Our desire is to have a reverberation time in the control room somewhat shorter than either of the studios it serves. Making it shorter than the 0.3 second of the speech studio, however, runs head on into another request. The control room acoustics has to be suitable for the occasional recording of interviews, etc., in that room. For evaluating speech studio sound in the control room, something like 0.25 second reverberation time would be best. For recording speech, it

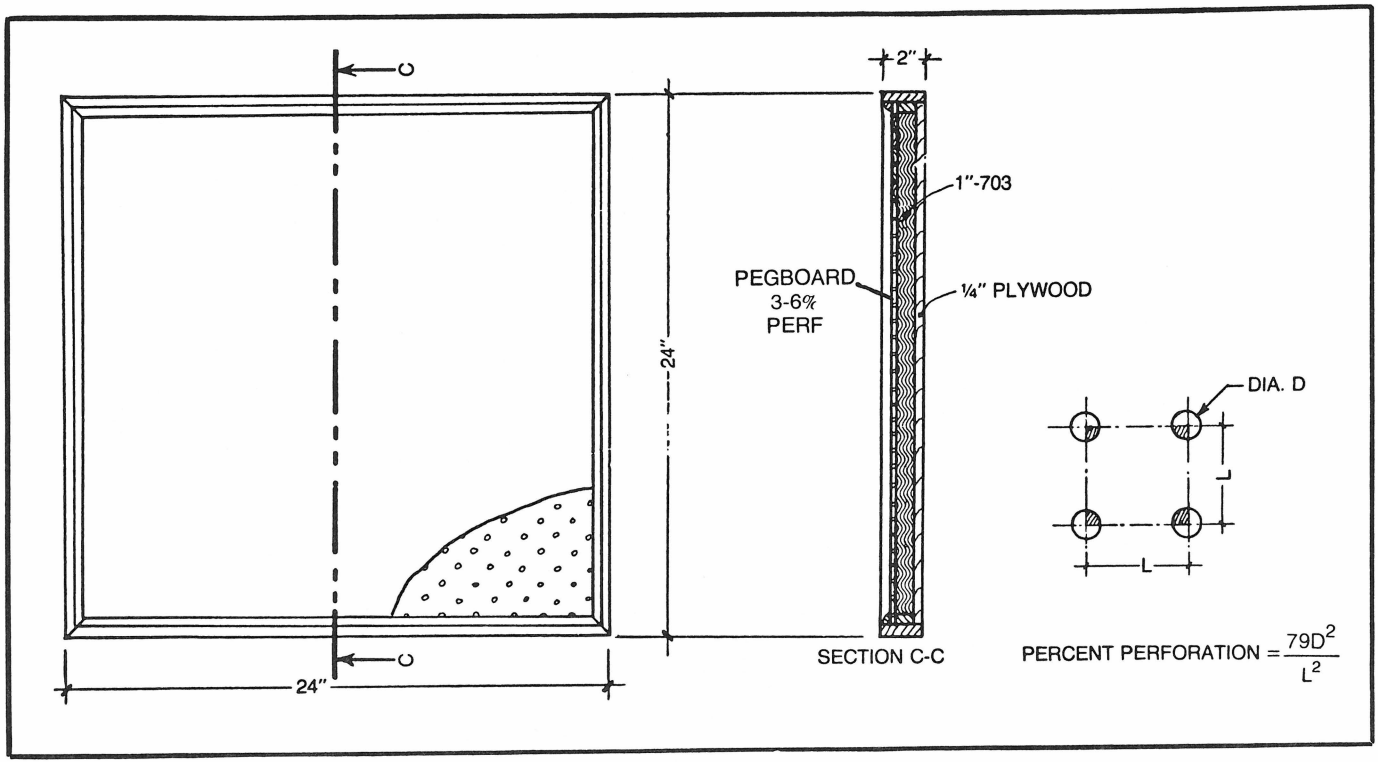


Fig. 10-11. Constructional details of mid peak (MP) absorber module used in speech studio.

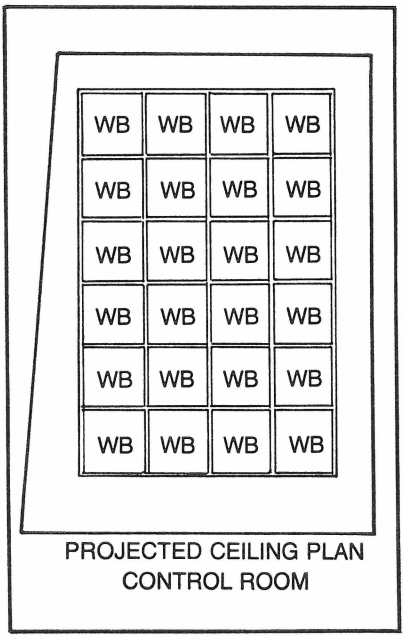


Fig. 10-12. Projected ceiling treatment plan of control room showing positions of 24 wide band (WB) modules.

should be 0.3 second. As a compromise, 0.28 second is used as shown in Fig. 10-8.

The treatment of the control room with its hard, reflective floor is a very straightforward task as only wideband (WB) modules are required. With a volume of 1550 cubic feet and surface area of 818 square feet it is easy to plug these figures and a reverberation time of 0.28 into Eyring's equation and come up with an average absorption coefficient of 0.282. Multiplying this by the area gives the total number of absorption units required to yield 0.28 second reverberation time, 231 sabins.

As shown in Fig. 10-12, 24 WB modules are mounted on the ceiling. Figure 10-13 shows 15 WB units on the north and 21 on the east walls of the control room. The enclosed cabinets under the work table, which are of ½ inch plywood enclosing an air space, must be considered panel absorbers. However, the 61 square feet of such a surface yields only about 17 sabins, hence the reverberation time is pulled down only a slight amount at the low end of the spectrum.

As all walls are masonry, their absorptive effect is negligible. Squeezing out a few sabins from the wood parquet floor

and glass surface the total 231 total is approached. If the walls were of drywall, the low frequency absorption could be significant. Absorption of walls and cabinets provide the only unbalanced absorptive effect in a room such as this, and it is usually of nominal magnitude.

AIR CONDITIONING

Tearing holes in studio walls comes under the heading of bad news to acoustical consultants. The client in the present case considered a central air conditioning system too expensive and elected to use wall-mounted room units and live with the resulting inconvenience, discomfort and increase in background noise.

The sectional view of Fig. 10-14 shows how an acoustical shield can be built over the face of the air conditioning unit to be used when quiet conditions are required. Two layers of ¾ inch particle board are used because its density is about 30 percent greater than plywood. Such a double panel offers 35 dB attentuation at 500 Hz on a mass law basis. The trick is to seal this lid around the edges in a way which will match or

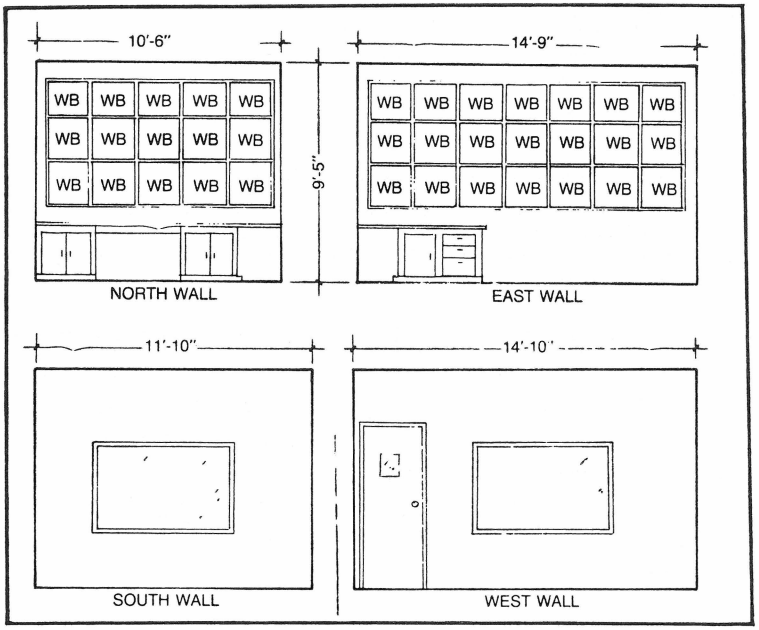


Fig. 10-13. Wall elevations of control room showing locations of wideband (WB) modules on north and east walls.

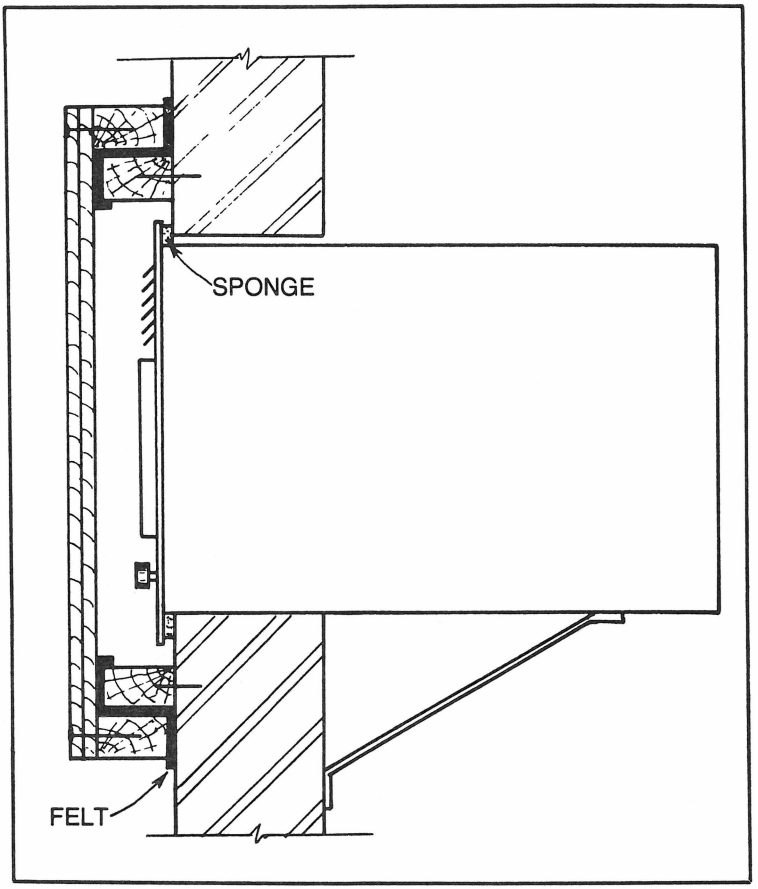


Fig. 10-14. Room type air conditioners are not recommended for sound sensitive areas, but if they must be used, the above plan provides reasonable protection against intrusion of outside noise. The A/C unit is turned off and the door closed during actual recording.

exceed this. Figure 10-14 shows an arrangement of a double 2 × 4 or 2 × 3 frame which can accomplish this if carefully constructed. The secret is well-caulked joints and use of heavy felt for a snug wiping fit. The lid may be hinged if desired and some device to clamp it in place is needed. This is not a very convenient solution of the air conditioning problem as the lid must be continually closed for a recording and opened to cool things off between takes.

Chapter 11
A Television Mini-Studio

Features: Adjustable acoustics, saw slot low peak resonators.

Recording studios of various types have been covered in previous chapters and it is time to consider one for television production. The client was not interested in commercial television production. Interest was centered in the training of television technicians to operate the camera, lights and control console as well as writers, producers and directors. This calls for a rather generous control room to accommodate the many observers in addition to those actually engaged in the task at hand. As there are no special requirements for the acoustics of the control room, this chapter will deal only with the studio. Not only was television training stipulated, the studio had to also be suitable for recording of musical groups and for speech in the form of dramatics, single narrator and interviews.

The acoustical requirements for TV, music and speech recording in the studio of Fig. 11-1 are quite divergent. The optimum reverberation time for speech for a studio of this size (7,418 cubic feet) is about 0.46 second; for music about 0.7 second. The requirements for television are less well defined as both speech and music are involved.

There is considerable noise produced in a TV studio as cameras are rolled around, cables dragged and the necessary

movement of personnel behind the camera. It is customary to use a boom-mounted microphone which can be brought only so close to those talking or it will dip into the picture. Even though the microphone is highly directional, the greater average source to microphone distance means that studio noise becomes a significant problem.

All of these things taken together have led the television production people to demand very absorbent walls and ceiling, the floor surface remaining hard to make rolling camera dollies and pedestals that much easier.

The requirements are much like the motion picture soundstage—make it as dead as possible. For both motion picture and television production, however, there is a saving grace in that the local acoustics are influenced strongly by reflections of sound from the walls of the setting. For example, if in the TV picture we see people in a library setting, reflections from the *flats* making up the visual bounds of the picture make the sound more or less what one would expect in a library in spite of one or two *open walls*. Movable absorptive flats are used to correct acoustical flaws which occur in such a fluid situation. A law of TV and motion picture production seems to be, "The next shot is entirely different!" Our goal, then, for television training work is to provide as dead a studio as feasible.

LOUVERED ABSORBERS

There are three acoustical conditions required: reverberation times of 0.46 and 0.7 second and a third even more dead than the 0.46 second speech condition. To meet all of these requirements in a single room demands some method of adjusting room acoustics. There are numerous ways the acoustics of a room can be varied.[4]

In Chapter 5 the possibility of flipping panels having one reflective side and one absorptive side was explored. Hinged panels can expose deep absorptive layers when open, cover them when closed and so on. The application of adjustable louvered panels as described in Fig. 11-2 seems to fit the present case best of all. The hardware of the louvered windows commonly used in homes in the more temperate climates can easily be adapted by using 3/16 inch tempered

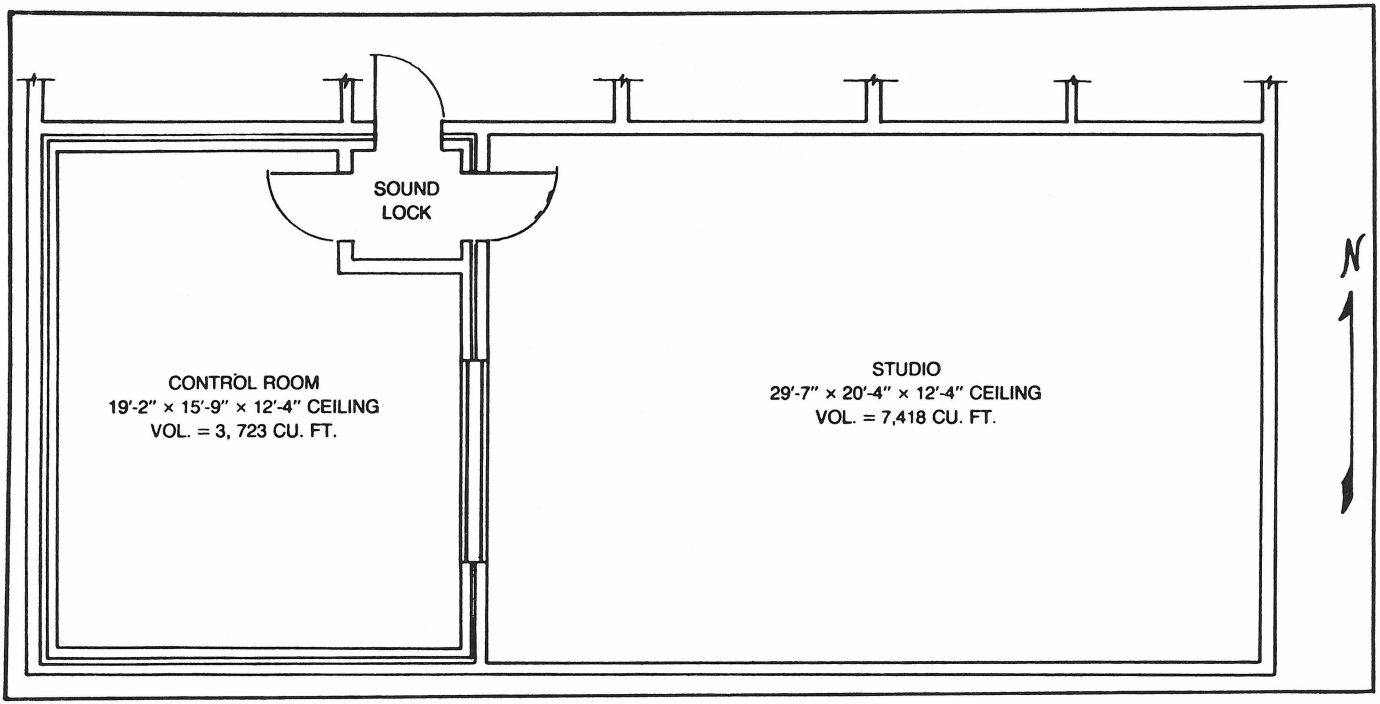


Fig. 11-1. Floor plan of studio suitable for television instruction and recording of speech, drama and music. The divergent requirements of these varied uses are met by adjustable acoustical elements in the studio.

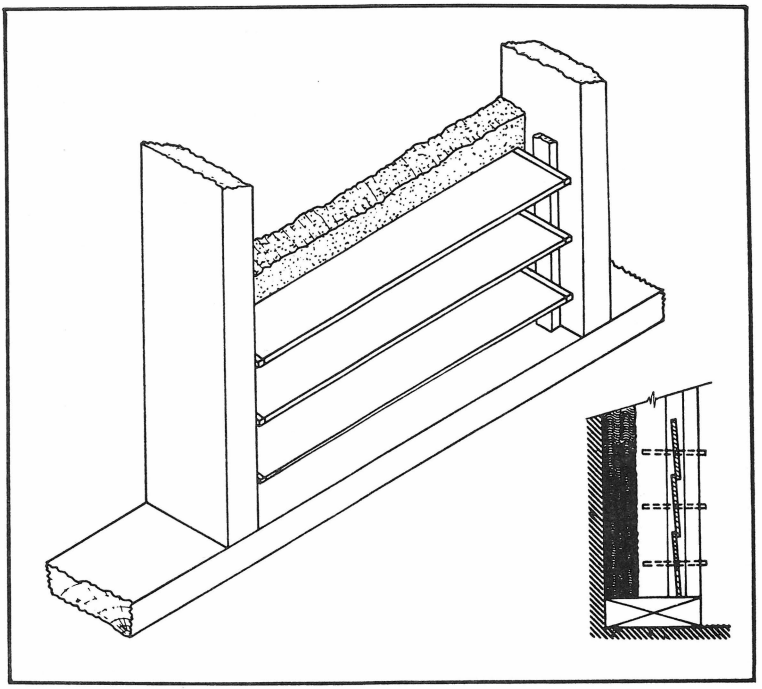


Fig. 11-2. Louver controlled adjustable absorber. The position of the panels (open or closed) controls the effectiveness of the 703 type of glass fiber behind. Partial closing of panels creates a Helmholtz resonator type of low peak absorber.

hardboard in place of the usual glass plates. Glass would be quite suitable acoustically, but far more expensive than hardboard. The simple movement of a lever opens and closes the panels of one segment, exposing the glass fiber behind when the panels are open (horizontal) and shielding it acoustically from the room when the panels are tightly closed. Adopting this means of adjustment of room absorption, the calculation of acoustical parameters of the room may proceed.

CYCLORAMA CURTAIN

To provide the neutral background so often demanded in television work, a cyclorama curtain arranged along the east and south walls is used as shown in Fig. 11-3. This curtain, supported from a curved track, may be moved or retracted at will. Assuming that this curtain is made of 14 ounce cotton material, it is a significant absorber, especially at the higher

audio frequencies. Besides being active as a visual background for TV, its deployment as shown in Fig. 11-3 also hides the low peak absorbers which are something less than beautiful. This does not cause an acoustical problem because the low frequencies upon which the low peak absorber acts are attenuated very little by the fabric.

FLOOR COVERING

A carpet, 200 square feet in area, is placed at the west end of the studio next to the observation window. Speech and drama activities could take place at this end of the studio. If the adjacent louvers on the north and south walls are open, something approaching the dead end of a live-end-dead-end studio could be arranged.

The floor not covered with carpet is covered with vinyl tile which is excellent for rolling camera dollies. In fact, the entire floor should be covered with vinyl tile, even under the carpet. For unusual situations the carpet can be rolled up or its location shifted at will.

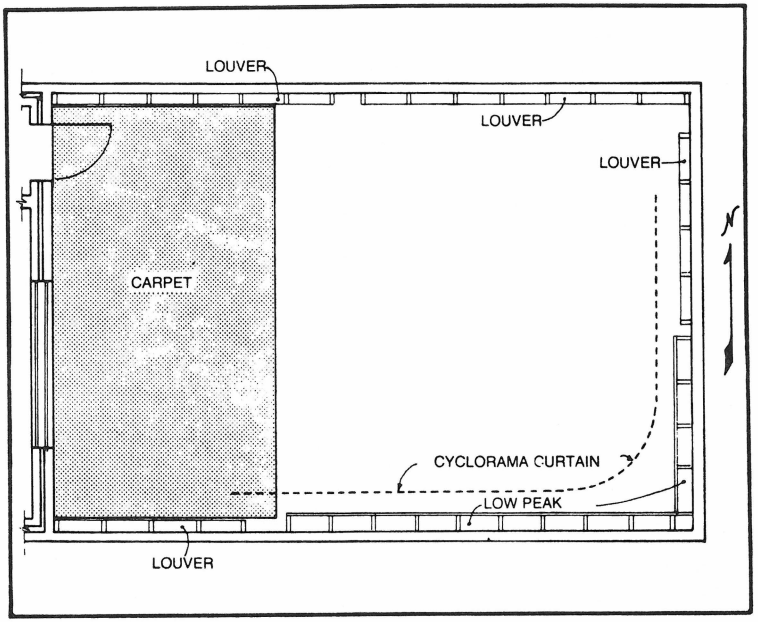


Fig. 11-3. Floor plan of TV and multipurpose studio showing positions of carpet, cyclorama curtain, low peak and adjustable louver absorbers.

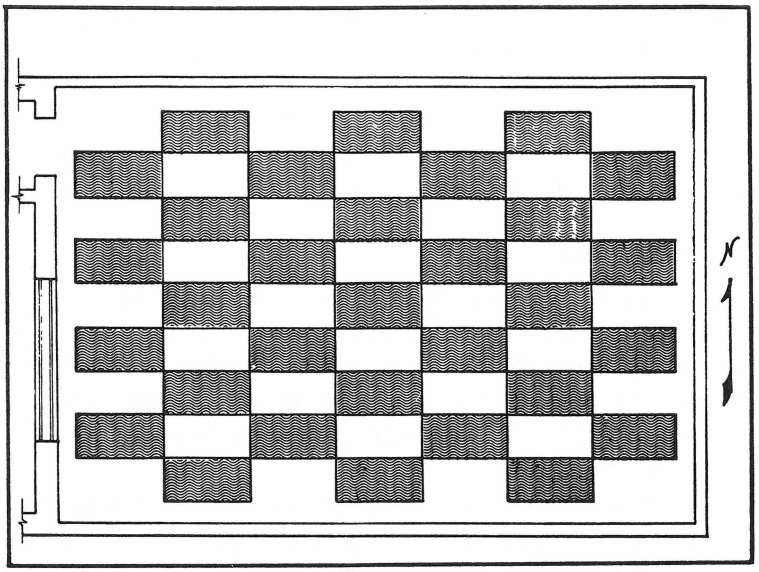


Fig. 11-4. Projected ceiling plan showing suggested pattern of 24 inch × 48 inch × 2 inch panels of glass fiber of 3 pounds per cubic foot density cemented to ceiling. These may be covered with thin cloth before mounting if desired.

CEILING TREATMENT

To keep the cost of acoustical treatment as low as possible a rather inelegant ceiling treatment is specified. A pattern of 31 panels of Owens-Corning Type 703 Fiberglas, 2 feet × 4 feet × 2 inches is cemented to the ceiling.

A suggested arrangement is given in the projected ceiling plan of Fig. 11-4. These semi-rigid boards (3 pounds per cubic foot density) should be relatively free from the sloughing off of troublesome glass fibers. If this is judged to be a problem, each panel could be wrapped in light weight cloth before cementing in place.

LOUVER ABSORBERS

The basic section of louver absorber is shown in Fig. 11-5. The frame is of 2 × 6 lumber. The width of each section is 24 inches inside. The height of the two lower segments of each section is 48 inches inside. This allows mounting the 2 inch 703 glass fiber with no cutting in the lower two segments and only a single cut for the top segment. The louvers can be adapted to the width of section selected (24 inches) by cutting

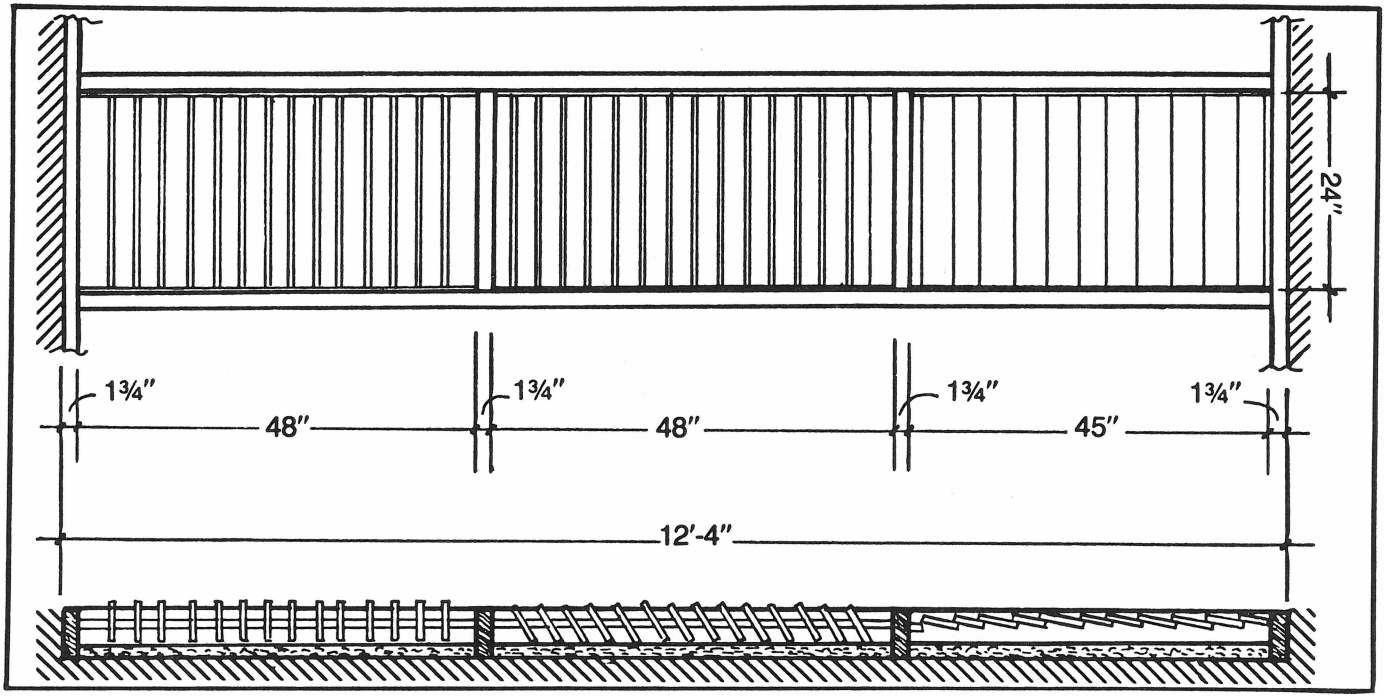


Fig. 11-5. Typical floor-to-ceiling louvered section. Construction of frame of 2 × 6s allows depth for only 2 inches of glass fiber. Using 2 × 8s would provide space for 4 inches of glass fiber.

the louver panels of 3/16 inch tempered hardboard the right length.

The louver sections are located in the studio as shown in Fig. 11-3. Thirteen louver sections are fixed to the north wall. By splitting the 13 into six and seven section groups a space is left near the center of the north wall for power and microphone outlets. Another group of four sections is similarly mounted on the east wall so that some wall surface is left exposed for electrical services in the NE corner of the studio. A fourth group of four louver sections is affixed to the west end of the south wall. A total of 21 floor-to-ceiling louver sections are thus distributed across three of the walls of the studio for a total of about 489 square feet.

Low Peak Absorbers

In certain foreign countries the specification of slat absorbers causes no problem because beautiful hardwoods are cheap and plentiful. Lumber costs in the United States have gone out of sight and buying straight-grained, good quality lumber is often ruled out by its cost.

To avoid such expense a low peak absorber using sheets of ¾ inch plywood with saw slots has been designed. This form of the familiar Helmoholtz low peak absorber is shown in Fig. 11-6. The frame work is made of 2 × 10 lumber spaced 24 inches center to center to accommodate the 4 foot × 8 foot sheet of plywood without waste. The cross bracing serves the double purpose of strengthening the structure and breaking the air space behind a single sheet of plywood into four cavities somewhat less than 2 feet × 4 feet each. This is important to discourage resonances in the cavity parallel to the plywood face. The slots are 4 inches center to center, arranged with respect to the 2 × 10 frame as shown in Fig. 11-6.

An uncertain factor in the design of this low peak absorber is the width of the saw slot, which affects tuning. A width of ⅛ inch is assumed in the present case, although increasing this to 3/16 inch would increase the frequency of resonance about 20 percent (from 144 Hz to 176 Hz for 4 inch spacing of slots). This is not too serious as the top of the resonance peak (the absorbence peak) is fairly broad if the 2

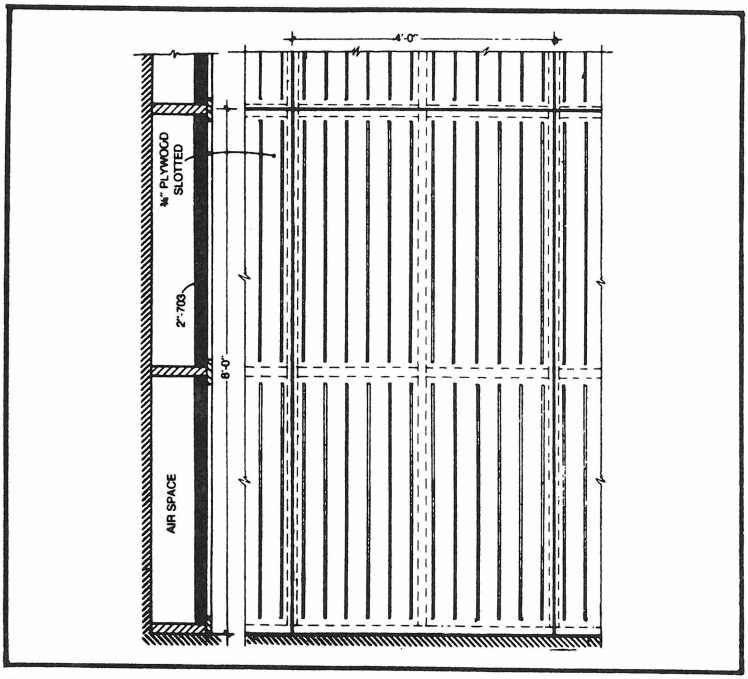


Fig. 11-6. Inexpensive low peak Helmholtz resonators on south and east walls made of ¾ inch plywood panels with saw slots cut in them.

inches of 703 glass fiber is placed against the back of the slotted panel where the air particle velocity is great.

Keeping the saw slot width between ⅛ inch and 3/16 inch should keep this shift of resonance peak within usable limits. The saw slots stop at the cross bracing to keep the 4 foot × 8 foot panel strong.

The glass fiber may be cemented to the back of the panel, spots of cement being placed between, but not close to, the saw slots. The saw slots should be cleaned out as much as possible, removing slivers and rough protrusions in the slots. A stain and varnish finish for the slotted panels is recommended, taking care not to clog the saw slots in the process.

Figure 11-7 summarizes the placement of acoustical materials and devices on the four studio walls. Because the cyclorama curtain hides most of the slotted panel absorbers, the visual impression on entering the room is that louvers cover most of the walls. This will, at least, give an impression of functional novelty, if not a thing of beauty and a joy forever.

Louver Complications

The practical aspects of louver controlled wideband absorbers have been discussed, but there is more to this type of structure than meets the casual eye. The simplistic view is that the louver is only a cover for the glass fiber boards which may be closed or opened. But what happens when the louver slats are not tightly closed, when a narrow slit remains? The slit makes that segment into a low peak absorber of the Helmholtz type. This is a very indeterminate condition. How wide is the slit?

A slit formed by two louver slats approaching each other is a far more complex problem, mathematically, than having a slit of fixed width in a cover of fixed thickness. Therefore, the frequency at which the absorption peak occurs is uncertain in using the louver elements as low peak absorbers, but the possibility is intriguing.

COMPUTATIONS

Table 11-1 gives the step by step calculations to the following three conditions:

- TV condition (all louvers open)
- Voice condition (1/3 of louvers open)
- Music condition (all louvers closed)

The resulting reverberation times for the three conditions of Table 11-1 are shown graphically in Fig. 11-8. The unbalanced absorption provided by the carpet, cylorama curtain and the low frequency deficiency of the 2 inch glass fiber ceiling boards are compensated by the saw slot low peak absorbers in varying degrees for the above three conditions. Consequently, the bass rise of the reverberation time of Fig. 11-8 is least for the TV condition and greatest when all louvers are closed for the music condition.

Now a confession: the construction of the louver sections detailed in Figs. 11-2 and 5 for 2 × 6 lumber allows only room enough for 2 inches of 703. The computations of Table 11-1 and the heavy line graphs of Fig. 11-8 are for 4 inches of 703 in all louver segments and sections. If calculations are carried through for 2 inches of 703 in all louver sections, the bass rise of reverberation time is much greater as shown by the broken

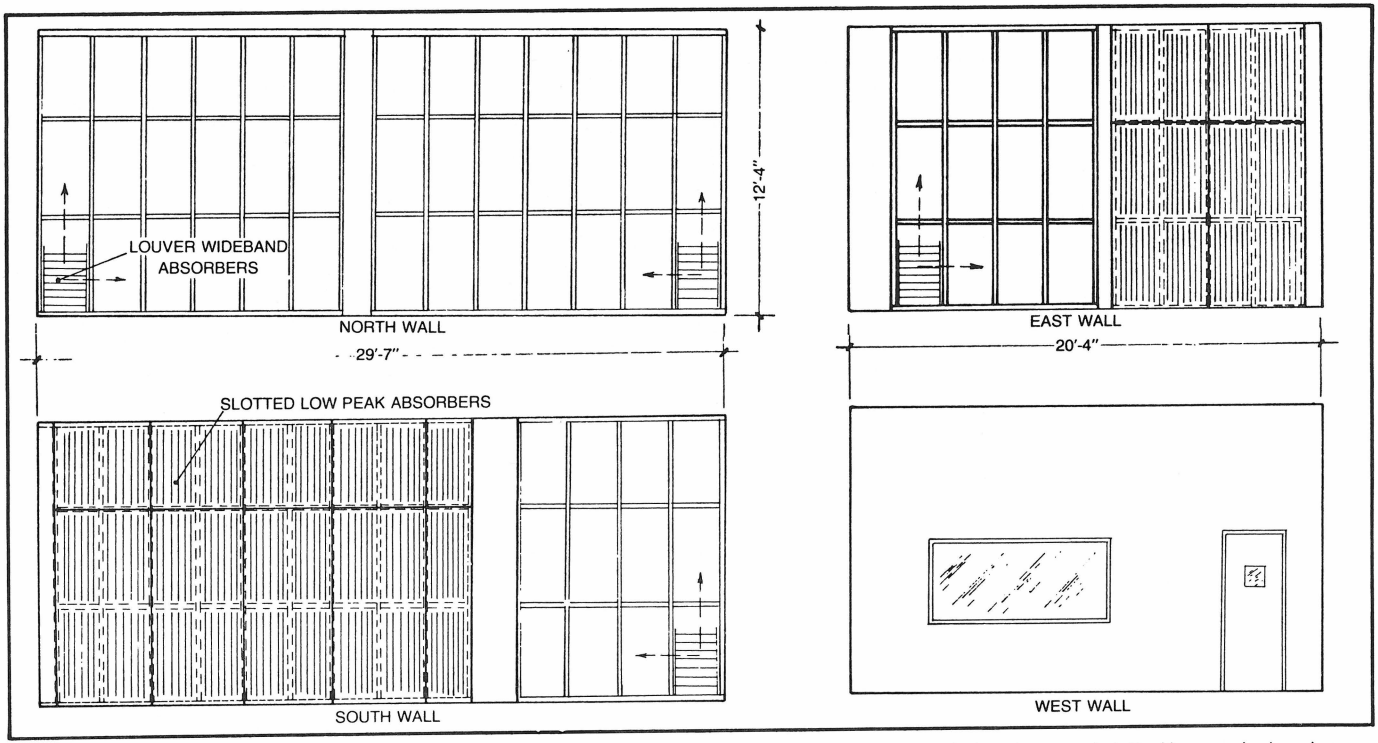


Fig. 11-7. Wall elevations of TV and general purpose studio showing placement of adjustable louvered absorbers and slotted low peak absorbers. The slotted absorbers are largely hidden by the cyclorama curtain.

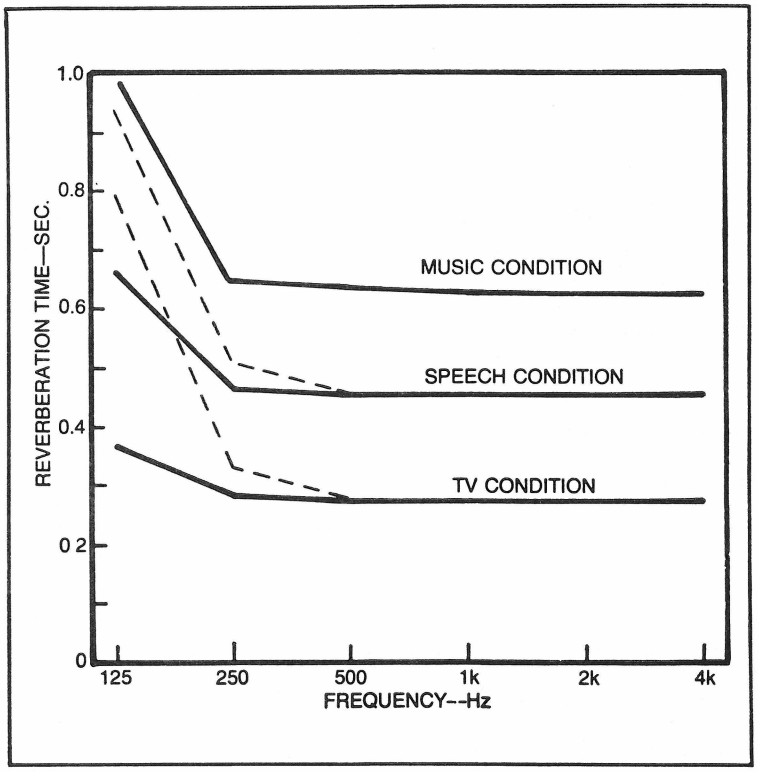


Fig. 11-8. Calculated reverberation time vs. frequency characteristic of studio for three conditions of adjustable louvers: TV condition (all louvers open), voice condition (⅓ of louvers open) and music condition (all louvers closed). The heavy lines apply to louvers with 4 inches of glass fiber, the broken lines apply with 2 inches of glass fiber.

lines of Fig. 11-8. Of course, changing the thickness of 703 has no effect on the music condition because all louvers are closed.

What is needed at this point is a series of detailed reverberation measurements for the specific studio in question. These should include measurements of reverberation time with different percentages of louvers in a narrow slit (low peak) and open condition.

Why go to the expense of 4 inches of 703 if 2 inches of 703 will work just as well using normally closed louvers as low peak slit resonators to compensate for the bass rise in reverberation time? This approach, obviously, requires some careful measuring and planning. It also requires some method, such

Table 11-1. Television Studio Calculations

SIZE ..... 29'-7" × 20'-4", Ceiling 12'-4"
FLOOR ..... Vinyl tile, 200 sq. ft. carpet, 3/16" pile, foam underlay
CEILING ..... 31 pieces 703 Fiberglas 2' × 4' × 2" cemented to ceiling
WALLS ..... Low peak absorbers, 278 sq. ft.
Louver adjustable wideband, 489 sq. ft., 4" 703
Cyclorama curtain, 35 lin. ft., 10' high, 14 oz mtl.
SURFACE AREA ..... 2,434 sq. ft.
VOLUME ..... 7,418 cu. ft.

MATERIAL	S Area sq. ft.	125Hz		250Hz		500Hz		1kHz		2kHz		4kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	200	0 05	10 0	0 10	20.0	0.10	20.0	0.30	60 0	0.40	80.0	0.50	100.0
Floor:vinyl tile	401	0.02	8.0	0.03	12.0	0.03	12.0	0.03	12.0	0.03	12.0	0.02	8.0
Ceiling:31/703	248	0 18	44 6	0 76	188.5	0.99	245.5	0.99	245.5	0.99	245.5	0.99	245.5
Cyclorama	350	0.03	10.5	0 12	42 0	0 15	52.5	0.27	94.5	0.37	129.5	0.42	147.0
Lo peak absorb	278	0.90	250.2	0 84	233 5	0.64	177.9	0 36	100.1	0.17	47.3	0.06	16.7
Sa Subtotal			323.3		496.0		507.9		512.1		514.3		517.2
TV CONDITION													
All louvers open 4" 703	489	0.99	484.1	0 99	484 1	0.99	484 1	0 99	484.1	0.99	484.1	0.99	484.1
Total sabins, Sa			807.4		980 1		992.0		996.2		998.4		1001.3
Ave. absorp. coeff., a		0.332		0.403		0.408		0.409		0.410		0.411	
Reverb. Time, Sec.		0.37		0.29		0.28		0.28		0.28		0.28	
VOICE CONDITION													
33.6% louvers open	164	0 99	162.0	0.99	162 0	0 99	162.0	0.99	162 0	0.99	162.0	0.99	162.0
Total sabins, Sa			485.3		658.0		669.9		674.1		676.3		679.2
Ave. absorp. coeff., a		0 199		0.270		0.275		0.277		0.278		0.279	
Reverb Time, sec		0.67		0 47		0.46		0.46		0.46		0.46	
MUSIC CONDITION													
All louvers closed													
Total sabins, Sa			323.3		496.0		507 9		512 1		514.3		517.2
Ave. absorp coeff, a		0.133		0.204		0.209		0.210		0.211		0.212	
Reverb Time, sec.		1 05		0 65		0 64		0 63		0 63		0.63	

as the use of a shim to set the slit width accurately in each segment. And it may be more straightforward to pay for 4 inches of 703 for the louver sections and live with the heavy graphs of Fig. 11-8.

However, the whole approach of using the louver sections as slit resonators could be reduced to simple operational procedures. If not followed, or carelessly followed, such operational procedures could result in some weird unbalanced acoustical conditions.

To calibrate judgment, a rough calculation has been carried through to help evaluate the use of louvers as slit resonators for supplying low frequency absorption.

In Fig. 11-9 the heavy graph A represents the reverberation time of the studio for voice condition with 2 inches of 703 in all louver sections. In this voice condition 1/3 of the louvers are open and 2/3 closed. Assuming that the slit width and depth (the overlap of the louvers), the effective cavity depth and all other parameters result in a low peak resonator comparable to the saw slot low peak absorbers, the absorption coefficients of the saw slot units can be used in this rough calculation (See Table 11-1). This is not a very secure assumption, hence the results may be off a considerable amount, but still be of help in a qualitative way.

With this assumption graphs B and C have been computed. Graph B is for 1/3 of the louvers open, 1/3 closed and 1/3 in low peak slit condition. Graph C is for 1/3 of the louvers open and 2/3 in slit condition. Graph C flattens out fairly well, but falls too far below the 0.46 second goal. Having 1/3 of the louvers open is common to all three graphs. Other combinations of open and slit louvers would undoubtedly lift and straighten graph C but, it is emphasized, this should be done on the basis of measurements, not calculations with uncertain coefficients.

TELEVISION FACILITIES

The cyclorama curtain has been discussed, perhaps a bit prematurely, in connection with its acoustical absorption effect. The relationship of this curtain to an overhead pipe grid for supporting lamps is shown in Figs. 11-10 and 11-11A.

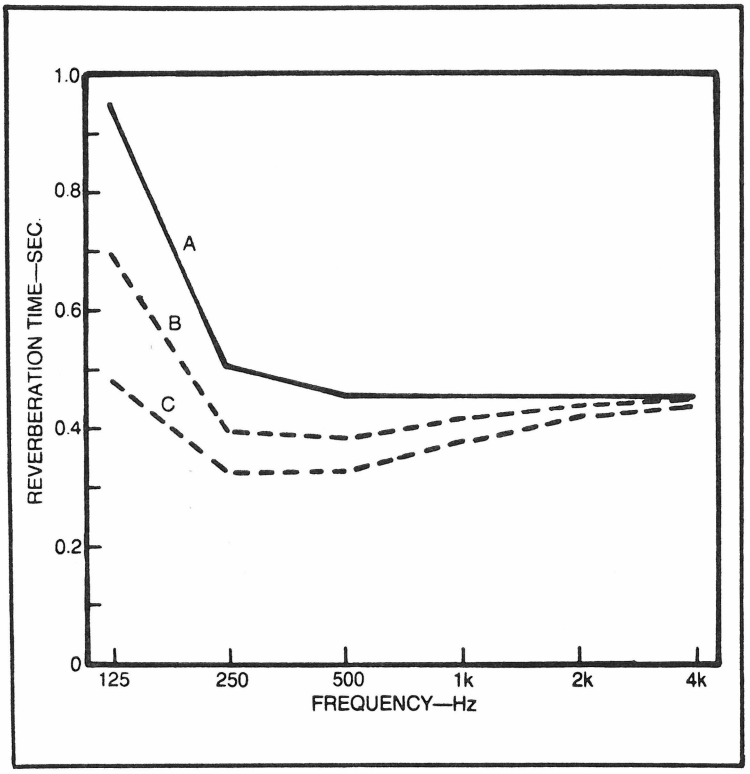


Fig. 11-9. Graph A is the reverberation time for the voice condition of Fig. 11-8 (⅓ louvers open with 2 inches of glass fiber) repeated for reference. Opening some of the closed louvers slightly converts them to low frequency slit absorbers. Graph B is for ⅓ of the louvers open, ⅓ closed and ⅓ in low peak slit condition. Graph C is for ⅓ of the louvers open and 2/3 in the slit condition. This illustrates the possibility of reducing the bass rise by using louvers in the slit condition.

The advantage of supporting lamps from above is that the floor is kept free of most lamp stands and cables. For full lighting it is sometimes necessary to provide a suitable *scoop* or *broad* on a stand, but a grid can care for most of the lighting equipment required for a small stage such as this.

The pipes, often 1-½ inches inside diameter, are secured at intersections with U-bolts as shown in Fig. 11-11B. The individual lamp units are suspended below the grid at an adjustable height on a vertical pipe secured to the grid by the toothed clamp also depicted in Fig. 11-11B. A safety chain from the pipe grid to the lamp unit is necessary as the adjustable devices sometimes slip.

Lamps are mounted, positioned, adjusted and pointed from a ladder. In large studios this is done from catwalks above. With one or more cameras, conventional acoustical treatment in the control room, videotape recorder, monitor bank, video and sound consoles and the required supporting

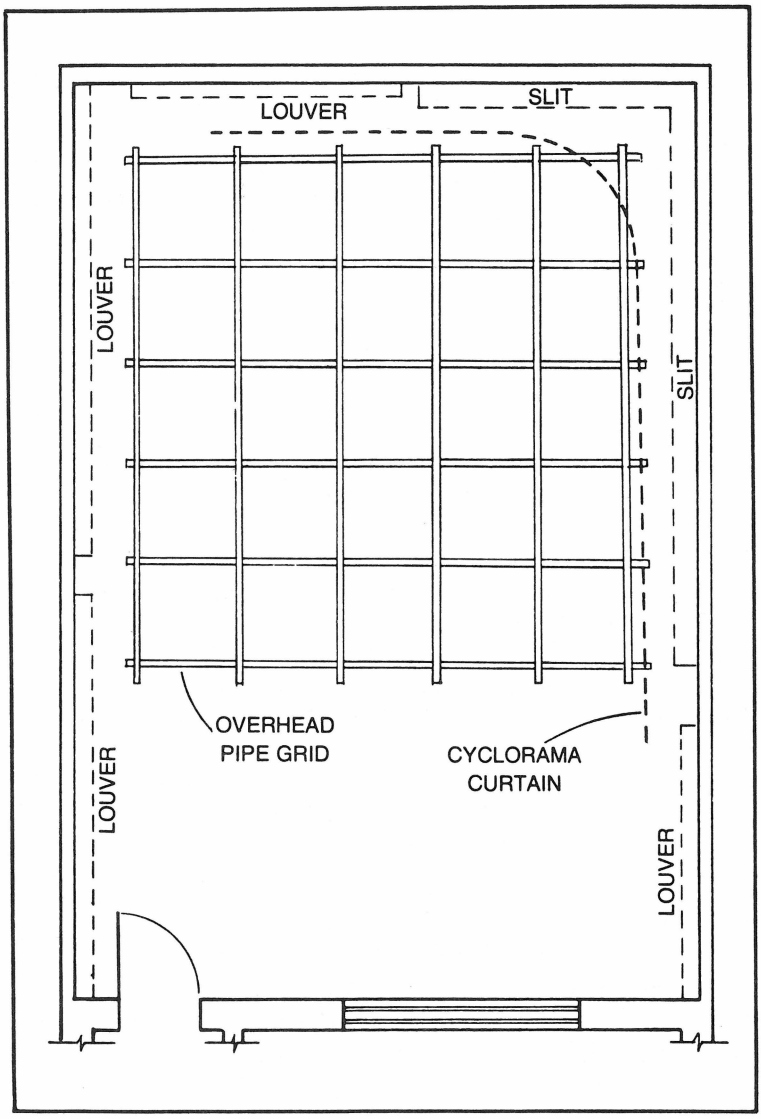


Fig. 11-10. Projected ceiling plan of TV general purpose studio showing relationship of overhead pipe grid for supporting lamps and the cyclorama curtain.

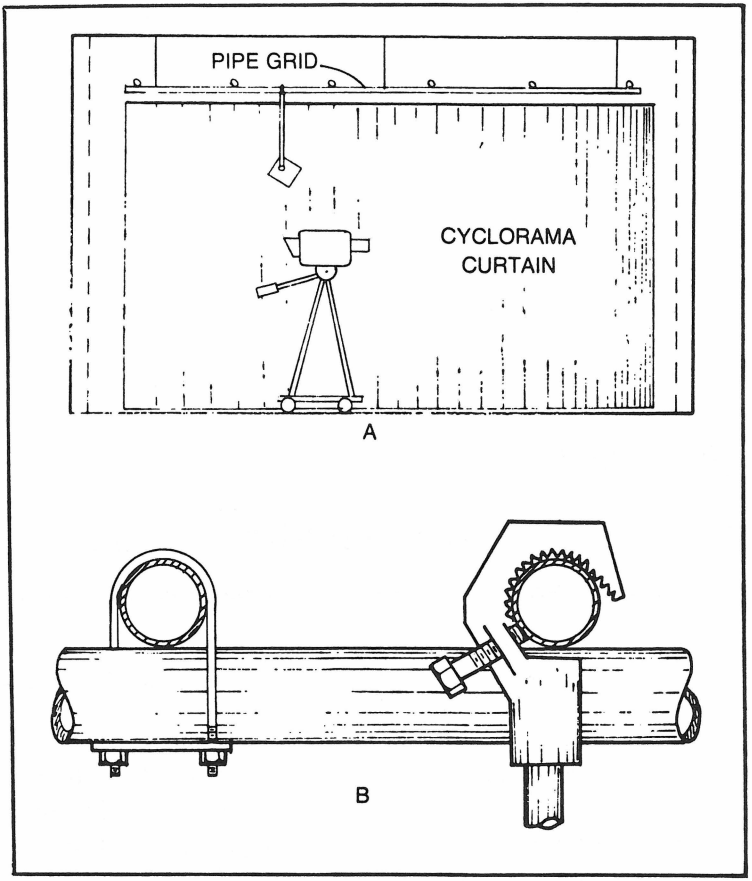


Fig. 11-11. (A) Overhead pipe grid for supporting lamps and its relationship to cylorama curtain. (B) U-bolt clamp method of securing pipe grid and conventional hook for lamp hangers.

gear, the TV mini-studio described should be quite adequate for a meaningful training program. An illustrated trade reference catalog is helpful in setting up such a television training facility.[36]

Chapter 12
A Television and Multitrack Studio

Features: Adjustable acoustics, using a small studio as an isolation booth, service boxes for microphones and television equipment.

What do television studios and multitrack recording studios have in common? Offhand, TV and multitrack seem like quite divergent activities. They both need ample space. In multitrack recording the acoustical separation between sources obtainable by screens and other devices is limited and it is soon discovered that a certain minimum of physical separation is necessary, which adds up to requiring a certain amount of floor space for each performer. Television's need for elbow room is more obvious, what with several cameras rolling around, overhead space for lights and multiple sets.

The studio selected for this chapter is, according to the general plan of this book, a budget project. This means compromises in many areas; the challenge is in keeping the magnitude of these compromises small. For example, the walls of this studio are 8 inch concrete block rather than double concrete with an air space. By plastering both faces and filling the block voids with concrete, a respectable STC56 can be obtained which is within range of, say, STC 62. This illustrates a

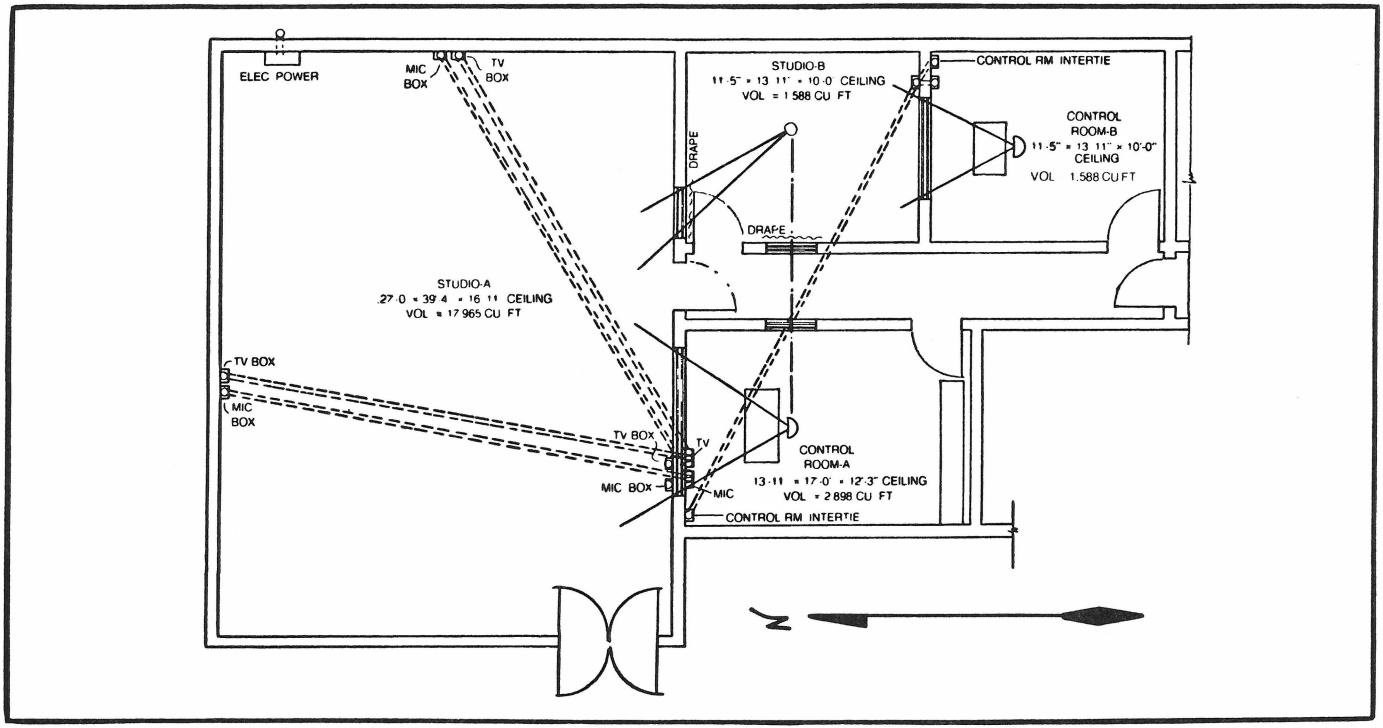


Fig. 12-1. Floor plan of larger studio complex adapted for both television and multitrack work. The use of Studio B for drum or vocal isolation booth is aided by small windows for visual contact and intertie lines between Control Rooms A and B.

physical principle not too generally appreciated—that it is the last ounce that boosts the cost to excessive levels.

Put another way, the curve flattens out so that much more effort and money must be put in to get that last ounce than the earlier ounces. The message is simply that work of quality can be done with facilities somewhat less than the world's best. The best studio in the world comes far from guaranteeing the best product; skill and resourcefulness are still the indispensible ingredients.

STUDIO PLANS

The layout of the studio to be studied is shown in Fig. 12-1. The plan includes two studio-control room suites. The large Studio A and its control room are for television and multitrack recording. The smaller Studio B and its control room are for general speech work.

Studio B serves also as an isolation booth for vocals or drums when complete separation from what is happening in Studio A is required. A window in Control Room A lines up with a window in Studio B for coordination of activities via eye contact. Another window in Studio B looking into Studio A does the same between those two rooms. These incidental windows for eye contact are small but are built to the same double glass standards as the larger observation windows.

CONDUITS

A suggested plan for conduit runs is indicated in Fig. 12-1. These conduits are layed before the floor slab is poured as shown in Fig. 12-2A. This gives the most direct path which pays off later in ease of snaking in the cables. Conduit terminal boxes are on the north and east walls. The boxes on the south wall under the control room window are fed directly through the wall from the control room as indicated in Fig. 12-2A. To avoid acoustical leaks these short conduits through the observation window wall must be very carefully caulked and after the cables are pulled through, glass fiber should be packed in the conduit from both ends.

One conduit serves television equipment and another holds the audio lines for each of the three terminal positions in

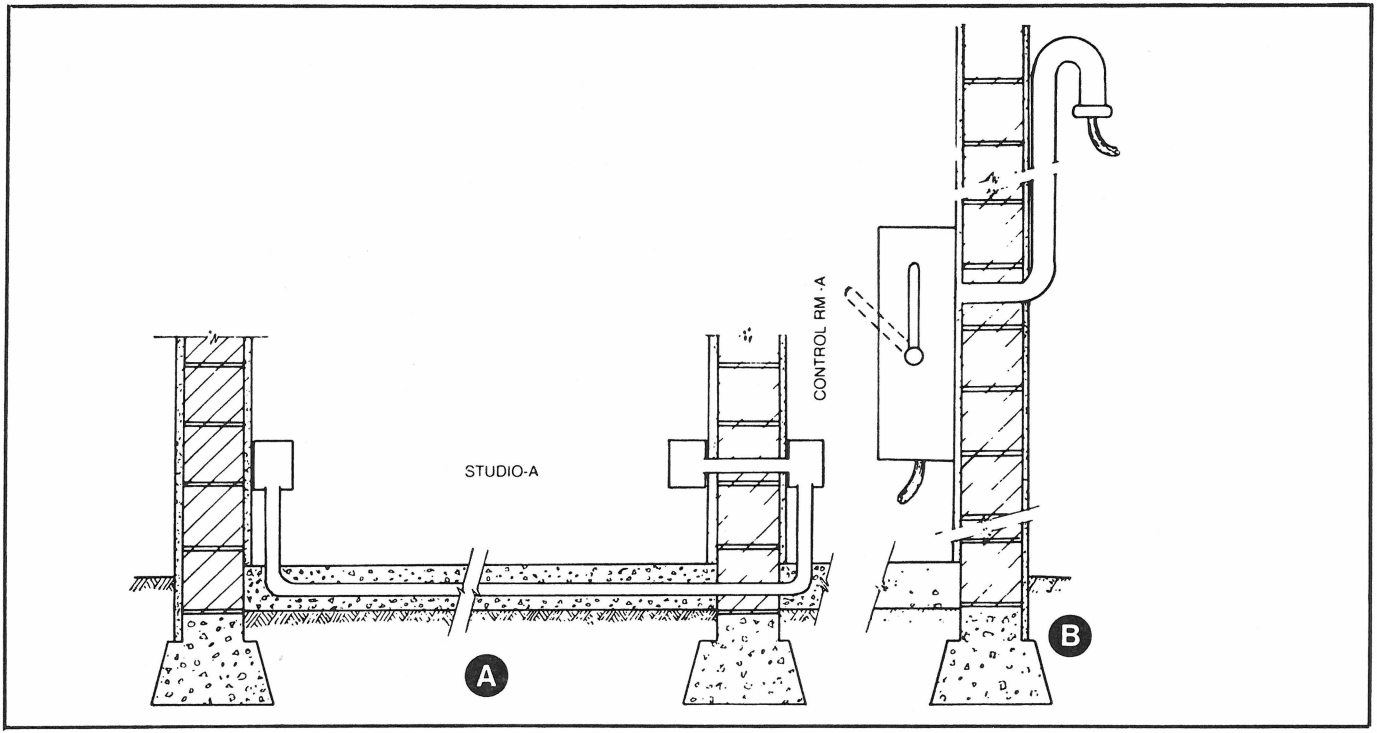


Fig. 12-2. (A) Duct runs layed before the concrete floor is poured provide separate ducts for television and audio use. (B) Electrical switch box arrangement for engergizing portable cable runs for all set lighting. House lights are handled in the conventional way.

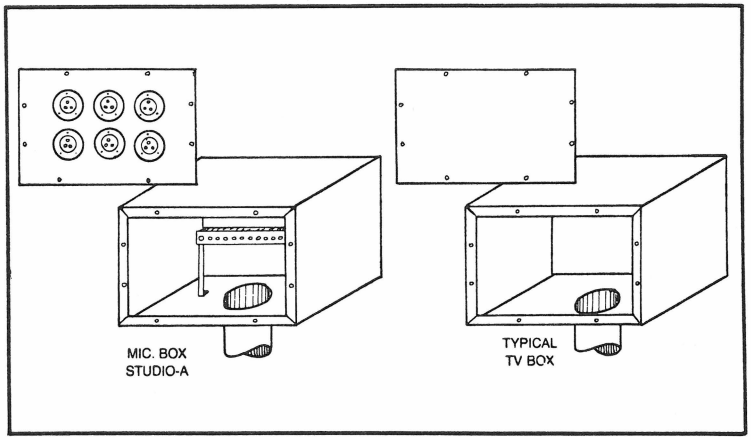


Fig. 12-3. Conduits are terminated in boxes adapted to audio or television use.

Studio A. These conduits are fitted with boxes of the type shown in Fig. 12-3. Each audio pair terminates on a barrier strip from which flexible leads run to the professional type microphone connectors mounted on the lid. The TV box must be adapted to the type of camera equipment to be used, but this is straightforward if the conduit and boxes are provided.

In the control room boxes larger than those in Studio A are required because they must terminate three conduits and the one going through the wall coming into the back of the box, if desired. Figure 12-2A and Fig. 12-4 illustrate one satisfactory method of arranging both TV and microphone boxes and conduits in Control Room A.

A conduit should always tie control rooms together in a studio complex. By running six audio pairs in this conduit and terminating at both ends on a jackstrip, great flexibility results. Equipment in Control Room B may be used for a big job in Control Room A, or vice versa, without moving the equipment physically. Using the lines for microphone, cue foldback or talkback is also made easy with these intertie lines. The intertie box is shown in Fig. 12-4.

POWER FACILITIES

Figure 12-2B gives details of the heavy duty electrical power switch and breaker box on the east wall of Studio A. This is to provide power only for set illumination. The general

house lights are handled independently in the conventional manner. From this box portable cables run to spider distribution boxes and then to the individual lamp circuits on the pipe grid and on the floor. When this switch is open, all portable circuits are dead. For safety, great care must be exercised around these heavy duty lamp circuits and only experienced personnel should be allowed to work with them.

STUDIO TREATMENT

It has been pointed out that both television and multitrack recording require relatively *dead acoustics*. The client also expressed a desire to have Studio A acoustics suitable for recording musical groups in the more conventional manner.

In fact, this use was in immediate demand while both TV and multi-track were activities they hoped to enter soon. To minimize the degree of compromise between the three types of work a certain amount of adjustability has been built into Studio A acoustical treatment. This is accomplished by seven swinging panels on the north wall and five (rather, four

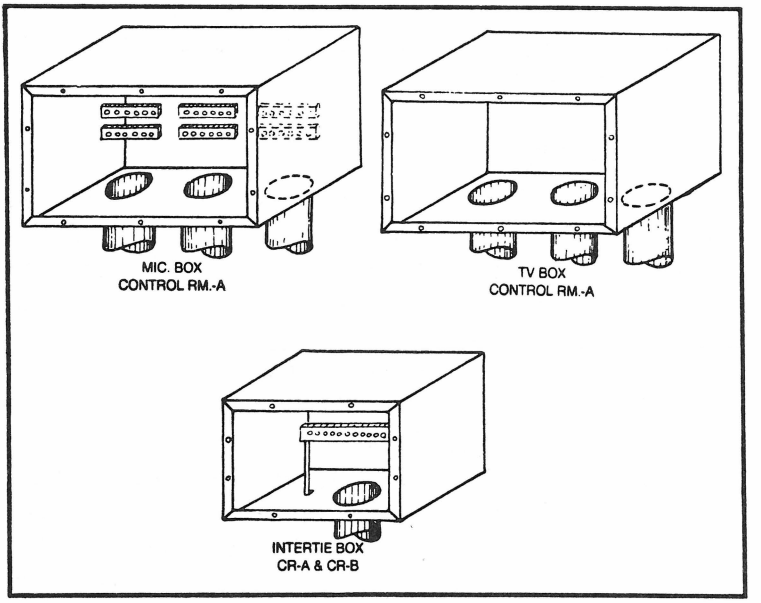


Fig. 12-4. In control Room A the microphone box must terminate three conduits; the television box the same. An intertie box terminates the conduit connecting Control Room A and Control Room B.

full panels plus a half panel) on the east wall as shown in Fig. 12-5. By closing all panels approximately 334 square feet of 2 inch 703 are, in effect, removed from the room and replaced by about half that area of plywood. The closed panels also are physical protrusions which assist in diffusing sound.

Swinging Panels

The swinging panel construction is detailed in Fig. 12-6A and 12-6B. It is a simple frame of 1 × 4 lumber, with a plywood back (½ inch or ⅝ inch) for stiffening, which holds and protects 2 inch thick Type 703 Fiberglas absorbent. For efficient plywood cutting the frame is made of a size to accept 2 foot × 8 foot pieces of plywood. A cross member at the midpoint adds strength, breaks the 8 foot length visually and supplies a logical position for a third hinge.

Some acoustically transparent protective cover is desirable for the 703. This could be perforated metal sheets having at least 25 percent of the area in holes. It could be expanded metal, such as metal lath, or wire screen. Perhaps the simplest and most attractive, if not the most resistant to mechanical damage, is colorful cloth such as burlap or other loosely woven fabric.

Plywood Wall Diffusers

Diffusers of ¾ inch plywood of triangular construction are used on the west wall and a portion of the south wall as shown in Fig. 12-5. On this figure the cross-sectional shapes are associated with each elevation. To utilize the plywood without waste each face is either 2 feet or 4 feet in width.

The 12 foot length uses plywood of that length, if available, or 8 foot plywood sheets may be extended because of the placement of the section dividers. A 2 × 4 ridge and frame provides the basic stiffening and nailing facilities required.

Figure 12-7 gives basic details of construction which apply to diffusers having either the 2 foot or 4 foot face width. These plywood diffusers, which are also fairly low frequency absorbers, may be painted without affecting their acoustical properties significantly.

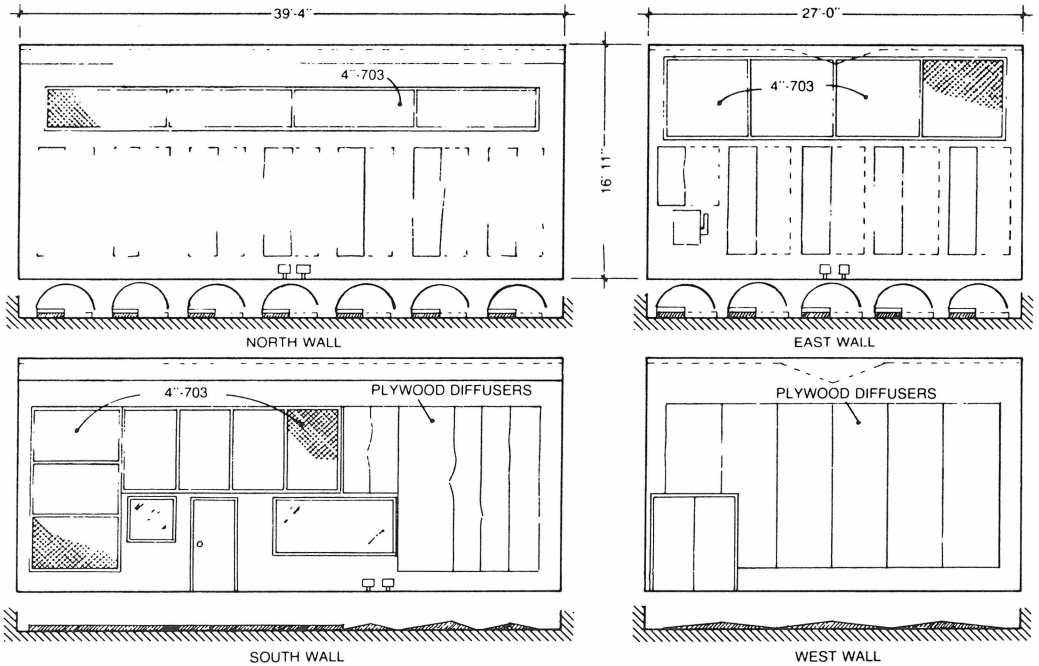


Fig. 12-5. Wall elevations showing treatment plan in large Studio A. Swinging panels on the north and east walls allow considerable range in adjustment of acoustics, supplementing plywood diffusers/absorbers and wideband elements.

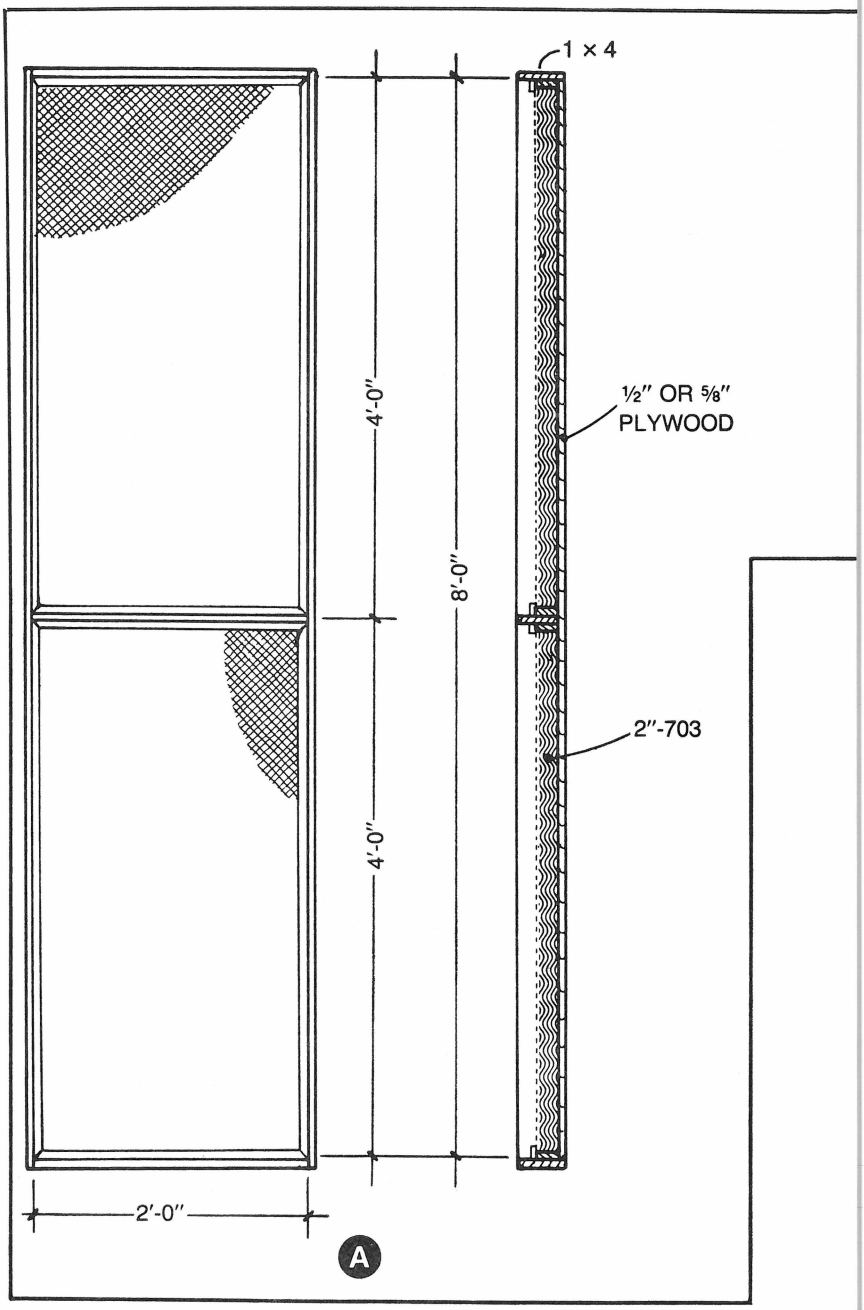
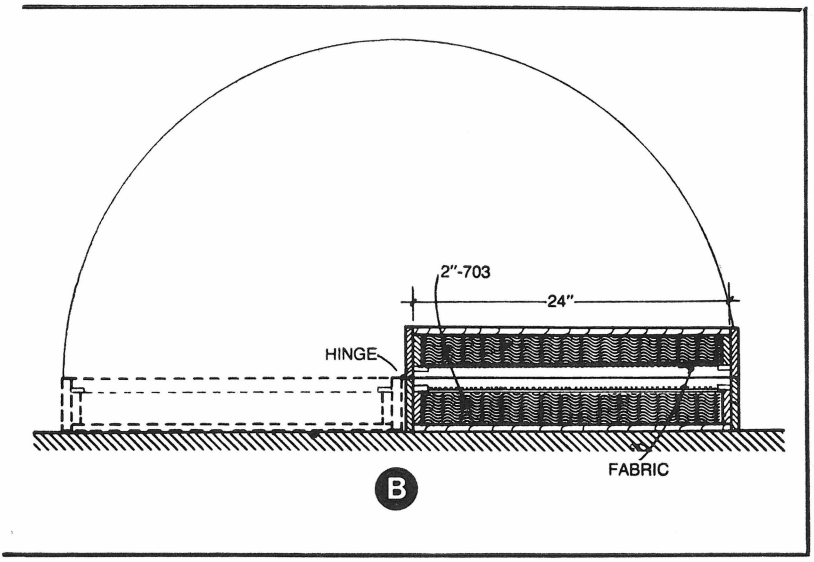


Fig. 12-6. Constructional details of 2 foot × 8 foot hinged wall panels. When open, double width of 2 inches of 703 is exposed. When closed, plywood protuberances contribute to diffusion and low frequency absorption.



Wideband Wall Absorbers

The east end of the south wall (Fig. 12-5) is largely covered with wideband modules containing 4 inch thicknesses of Type 703 Fiberglas. Modules of similar construction but of different shape are also mounted above the plywood diffusers on the north and east walls. The exact dimensions of the individual modules are not significant. The total effective area is significant.

As similar units have been described in earlier chapters, no space will be given to their construction other than to mention the need for a frame of 1 inch lumber (plywood backs are optional) and a light weight, loosely woven fabric for appearance and control of glass fiber particles. A perforated metal sheet (25 percent perforation minimum), screen or expanded metal cover may be added for protection against physical abuse if desired.

Ceiling Treatment

The Studio A projected ceiling plan of Fig. 12-8 reveals a triangular plywood diffuser approximately 8 feet wide running the length of the room down the center. The remainder of the ceiling surface is covered with a wideband absorber composed of the usual 4 inches of 703 Fiberglas.

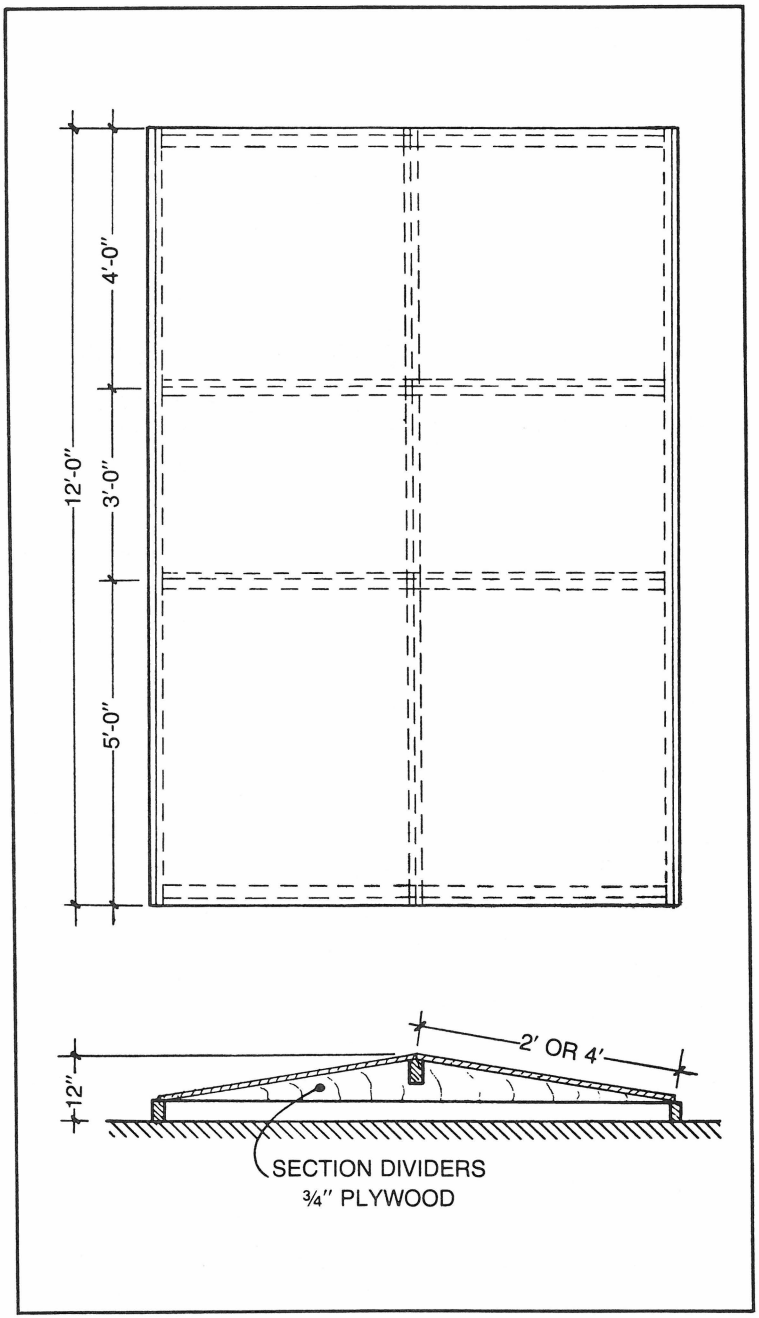


Fig. 12-7. Constructional details of fixed plywood elements on west and south walls. Panels of 2 foot and 4 foot width are utilized.

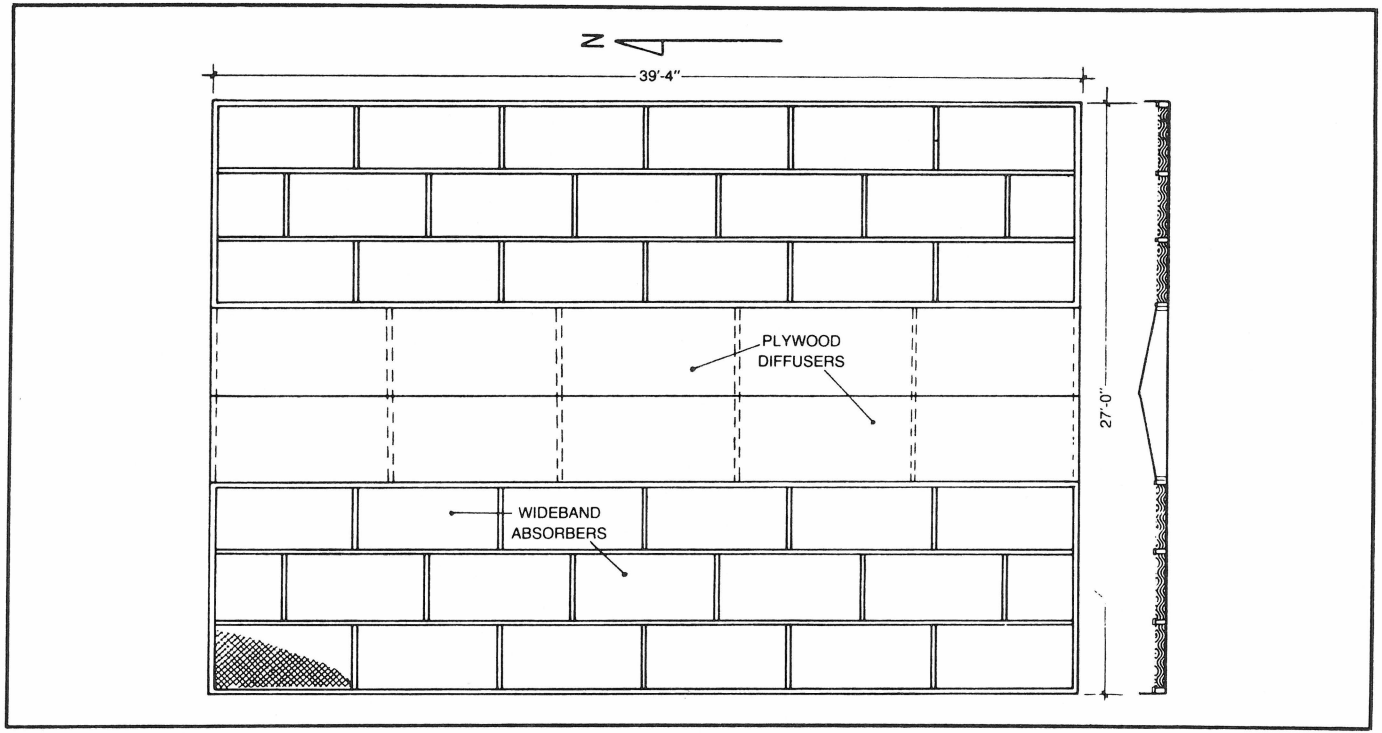


Fig. 12-8. Projected ceiling plan showing ceiling treatment. A triangular cross section plywood element about 8 feet wide runs the full length of the room. The remainder of the ceiling area is covered with 4 inches of 703 wideband sections.

Table 12-1. Studio A Acoustical Data

SIZE ..... 27'-0" × 39'-4", ceiling 16'-11"

FLOOR ..... Vinyl tile on concrete

CEILING ..... ¾" plywood diffuser-304 sq ft
Wideband 4" 703-722 sq ft

WALLS ..... Swinging panels 2" 703-334 sq ft
Wideband 4" 703-449 sq ft
¾" plywood diffuser-297 sq ft

SURFACE AREA ..... 4,368 sq ft

VOLUME ..... 17,965 cu ft

MATERIAL	S Area Sq. Ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Plywood: wall + ceiling	601	0 38	228 4	0 19	114 2	0 06	36 1	0 05	30 1	0 04	24 0	0 04	24 0
Wideband, 4 703: walls + ceiling	1171	0 99	1159 3	0 99	1159 3	0 99	1159 3	0 99	1159 3	0 99	1159 3	0 99	1159 3
Swing Panels OPEN: 2" 703	334	0 18	60 1	0 76	253 8	0 99	330 7	0 99	330 7	0 99	330 7	0 99	330 7
Total sabins, Sa			1447 8		1527 3		1526 1		1520 1		1514 0		1514 0
Ave Absorpt. Coeff., a			0 331		0 350		0 349		0 348		0 347		0 347
Reverb. Time, sec.			0 50		0 47		0 47		0 47		0 47		0 47
Swinging Panels CLOSED: Wideband, 4 703			1159 3		1159 3		1159 3		1159 3		1159 3		1159 3
Pywood: Walls + ceiling + panels	768	0 38	291 8	0 19	145 9	0 06	46 1	0 05	38 4	0.04	30 7	0 04	30 7
Total sabins, Sa			1451 1		1305 2		1205 4		1197 7		1190 0		1190 0
Ave. Absorp. Coeff, a			0 332		0 299		0 276		0 274		0 272		0 272
Reverb Time, Sec			0 50		0 57		0 62		0 63		0 63		0 63

A 2 × 4 gridwork holds the glass fiber semi-rigid boards which may be covered as discussed previously. In this case, expanded metal lath without the usual fabric is sufficient because of the height of the ceiling and the resulting distance from critical eyes and probing fingers.

The triangular plywood ridge on the ceiling is constructed as shown in Fig. 12-9. The entire structure is built down from the 2 × 4 gridwork fastened securely to the roof slab. There is a significant amount of open space between the plywood skin and the concrete roof slab. This space may be put to good use for conduit runs or, possibly even as a duct for air circulation.

Reverberation Time

Table 12-1 provides a summary of pertinent acoustical data and computations of reverberation time. This table has been simplified and abbreviated by neglecting the sound absorbed by the vinyl tile covered concrete floor, the plastered concrete block wall areas not covered by plywood or wideband units, windows, doors and air contained in the room. Admittedly, the absorbence of each of these is minor, yet our overall accuracy would be improved by their inclusion. But the price

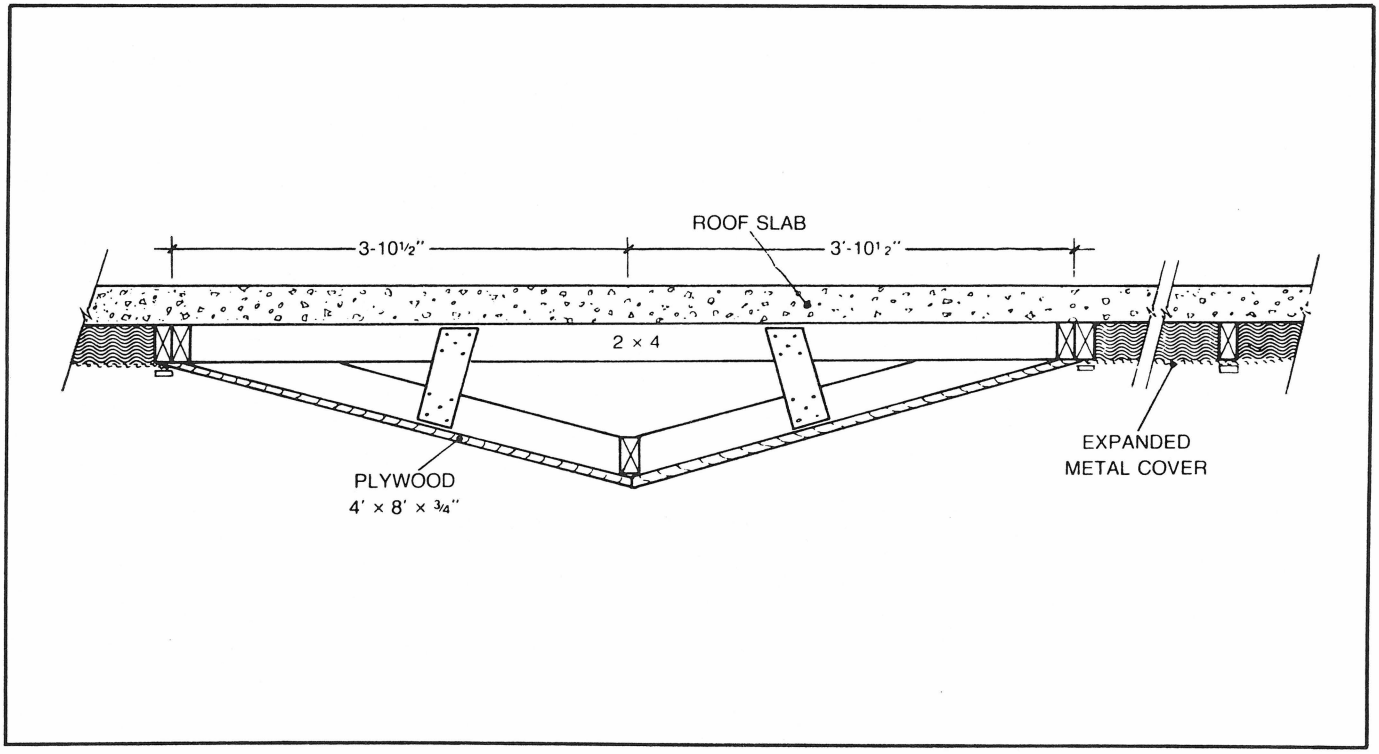


Fig. 12-9. Details of construction of ceiling plywood diffuser/absorber.

paid in confusion and complication is too high. Measurements should be relied upon for final evaluation in any event.

Table 12-1 includes reverberation time calculations for two conditions:

- All swinging panels open exposing the 2 inch 703.
- All swinging panels closed, covering the 703 and exposing the plywood box of half width and double depth.

The values of reverberation time from the table are plotted in Fig. 12-10 to give a graphical picture. It is interesting that at 125 Hz the reverberation time is essentially the same whether the panels are open or closed.

The 2 inches of 703 has an absorption coefficient of only 0.18 at 125 Hz, effective when the panels are open. When closed, the plywood shows a coefficient of 0.38, but this applies only to about half the area of the 703.

For frequencies of 250 Hz and above at which the 703 becomes essentially a perfect absorber there is a significant spread between the *all panels closed* and the *all panels open* graphs. When the panels are open a reverberation time of 0.47 second is obtained over most of the band. When closed, this increases to about 0.63 second.

Traditional music recording techniques would normally require a reverbertion time of about 0.9 second for a studio of this size (almost 18,000 cubic feet). However, 0.63 second constitutes a reasonable and usable compromise. For television and multitrack work the 0.47 second should be very favorable. Placing some of the musicians near the highly absorbent opened swinging panels, with adequate screens between, should result in excellent separation for multitrack work. Further, the thousand square feet of floor space should accommodate something like 20 musicians of either the traditional or multitrack types.[14]

For practically infinite separation, sometimes required for soloist or drums, the use of Studio B as an isolation booth is possible. The arrangement of Fig. 12-1 makes this both possible and convenient, sending the microphone outputs from Studio B to Control Room A by way of the intertie lines between Control Rooms A and B. Studio B, in the present

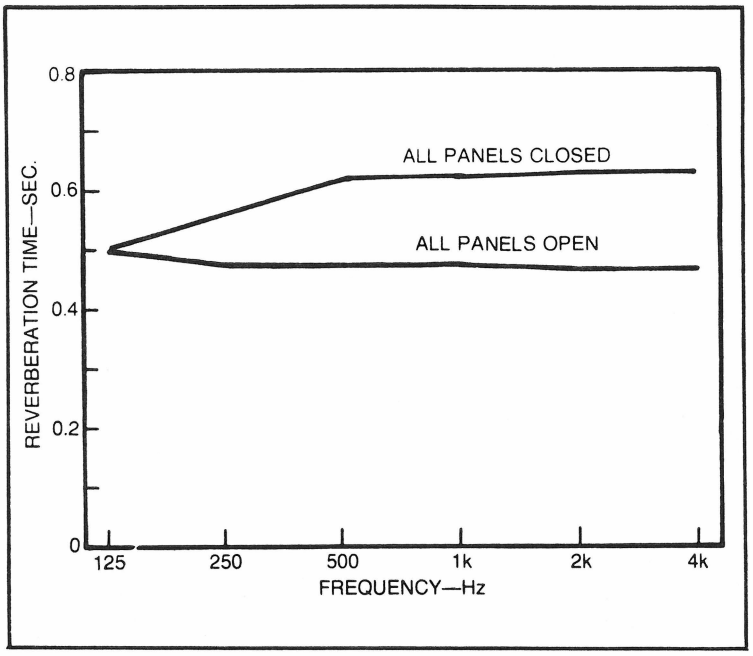


Fig. 12-10. Studio A calculated reverberation time characteristics for all panels closed (conventional music condition) and all panels open (multitrack and television condition). Swinging the panels has practically no effect at 125 Hz because the lower absorption of the 2 inches of 703 is offset by the plywood absorption of the closed boxes.

case, has a heavy work load in conventional recording of radio programs with a single narrator.

CONTROL ROOM TREATMENT

The wall treatment of Control Room A to achieve a reverberation time of about 0.3 second is described in Fig. 12-11. By plugging 0.3 second reverberation time into Eyring's equation we find that about 390 sabins (absorption units) are required. How shall this be distributed between the three pairs of room surfaces? This is an excellent opportunity for illustrating the good acoustical practice of distributing each type of absorber between the N-S, E-W and vertical pairs of surfaces in proportion to the areas of these pairs. In this control room with no carpet, we have only one kind of absorber—areas of 4 inch 703. In the case of Control Room A this distribution is shown in Table 12-2.

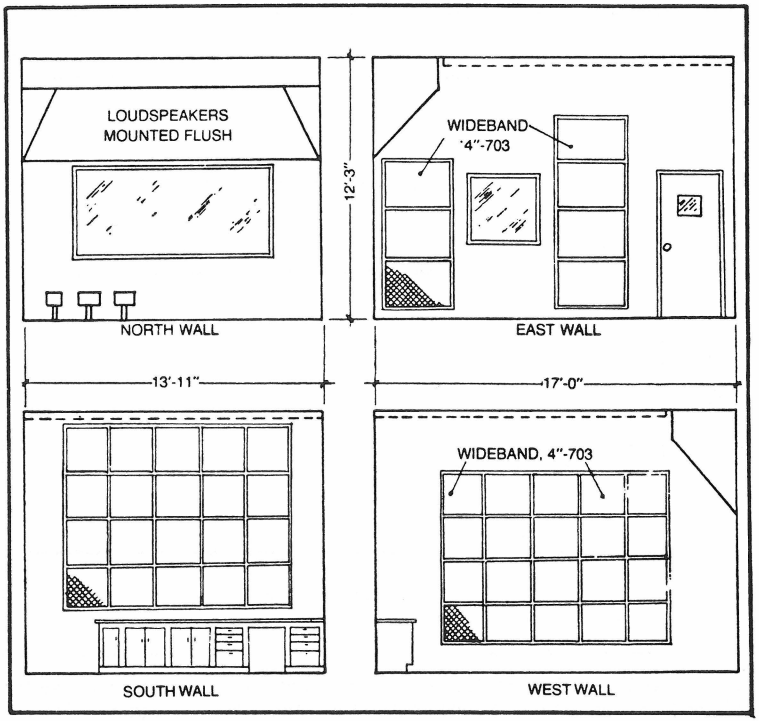


Fig. 12-11. Control Room A wall elevations. As vinyl tile is specified for floor covering, the only material required for acoustical treatment is 4 inches of 703 glass fiber.

For the frequency range 125 Hz-4 kHz we can take the absorption coefficient of 4 inches of 703 as essentially unity. This means that one sabin of absorption is given by each square foot of 703. For Control Room A we then need 390 square feet of 703. This should be distributed approximately as shown in column (a) of Table 12-2. About 132 square feet of 703 should then be applied to north and/or south walls, but we encounter a north wall almost filled with the observation window. The south wall has the work table and built-in drawers and cabinets. So, we do what we can and mount a frame of 20 sections, each 24 inches × 24 inches inside, on the south wall, totalling only 80 square feet. We resolve to place the other 52 square feet elsewhere. This is about all that can be done for the N-S mode.

How about the east and west pair of walls? On the west wall (Fig. 12-11) there are 20 sections, each 24 inches × 24

inches inside, yielding 80 square feet and seven sections 24 inches × 36 inches inside on the east wall. This gives an effective area of 42 square feet for a total of 122 square feet. The E-W walls then offer a total of 80 plus 122 or 202 square feet of 4 inch 703.

Ceiling Treatment

A total of 390 square feet of 703 is required and 202 square feet are applied to the walls, therefore 188 square feet must be applied to the floor-ceiling pair of surfaces. Because 703 is not a very satisfactory floor covering, this 188 square feet must all be placed on the ceiling. With a width of 13 feet-11 inches (13.9 feet), this means that a length of about 13.5 feet of 703 area would yield an area of 188 square feet.

The frame takes up a respectable portion of this area, hence a length of 14 feet-6 inches is actually required to give the 188 square foot net.

Figure 12-12 shows a grid of sections mounted on the ceiling, leaving some bare ceiling for the loudspeakers on the north end. The 24 inch inside dimension of each section is for the purpose of efficient cutting of the 24 inch × 48 inch sheets of 703. Of course, 24 inch × 48 inch sections would require

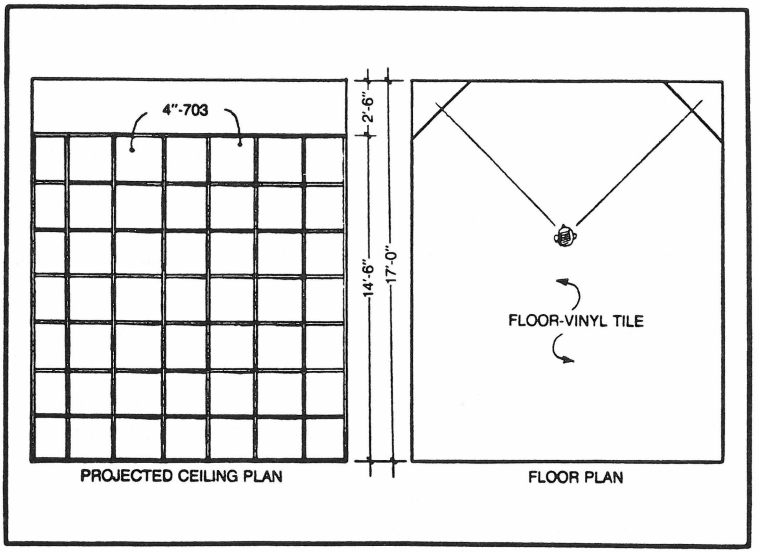


Fig. 12-12. Projected ceiling plan and floor plan of Control Room B.

Table 12-2. Control Room A Distribution

Axial Modes	Area sq. ft.	% Total area	(a) Exact distribution of 390 sabins	(b) Practical distribution 390 sabins
N-S walls	416.5	33.8	131.8	80
E-W walls	341.0	27.7	108.0	122
Floor-ceiling	473.2	38.5	150.2	188
Totals	1230.7	100.0%	390	390

cutting only in the odd sections. It is the 703 area that counts. There are many ways to handle the mechanical mounting.

The rationale of Table 12-2 is based on distributing the 4 inch thick 703 glass fiber material in proportion to the areas of the surfaces associated with the three axial modes of Control Room A. Column (a) of this table gives the exact number of sabins for each pair of surfaces based on this premise. Column (b) lists the practical distribution of 703 areas of Figs. 12-11 and 12-12. There are some unavoidable slips betwixt theory and practice. Observation windows, doors, hard surfaced floor and work table have brought compromise. The principle is still a good initial guide, even if certain departures from it are necessary.

Floor Treatment

As indicated in the floor plan of Fig. 12-12, the floor covering specified is vinyl tile. Linoleum, wood parquet or other hard surface is acceptable. By avoiding carpet with its unbalanced absorption, only 4 inch 703 is required in the acoustical treatment.

In the context of this chapter no detailed discussion of the treatment of Studio B and Control Room B is required because of their similarity to suites covered in previous chapters. For normal use of Studio B a reverberation time of the order of 0.3 second would be required. The suitability of 0.3 second when used as an isolation booth depends on the type of sound source placed in it. As a vocal booth 0.3 second may be a bit low but reverberation can always be added electronically. As a drum

booth it should be satisfactory as it is, although idiosyncrasies of individual drummers will often require temporary adjustments. For normal use of Studio B, short drapes may be drawn over the two unused windows to minimize reflection defects.

Chapter 13
Film Review Theater

Features: Listening room characteristics, projection facilities, stepped seating area.

Favorable conditions for viewing motion pictures must include both visual and aural factors. Visual quality depends on screen diffusion, screen brightness and steadiness of projected image. Aural quality in regard to room acoustics is much the same problem as covered in previous discussions of studio and monitoring room quality with some relaxation of tolerances. From the viewpoint of sound reproduction the motion picture projector sound head quality is vitally important along with amplifiers and loudspeakers. Both the visual factors and the acoustical will be treated in this chapter as they are inseparably bound together in projecting motion pictures effectively.

FLOOR PLAN

For the best impression of a projected motion picture the projection machinery must be in a separate room. This not only reduces the noise, it eliminates one more potential diversion of attention of those who should be paying full attention to the screen.

In Fig. 13-1 a very practical, low cost, high quality screening facility is described. It is small, but effective, accommodating

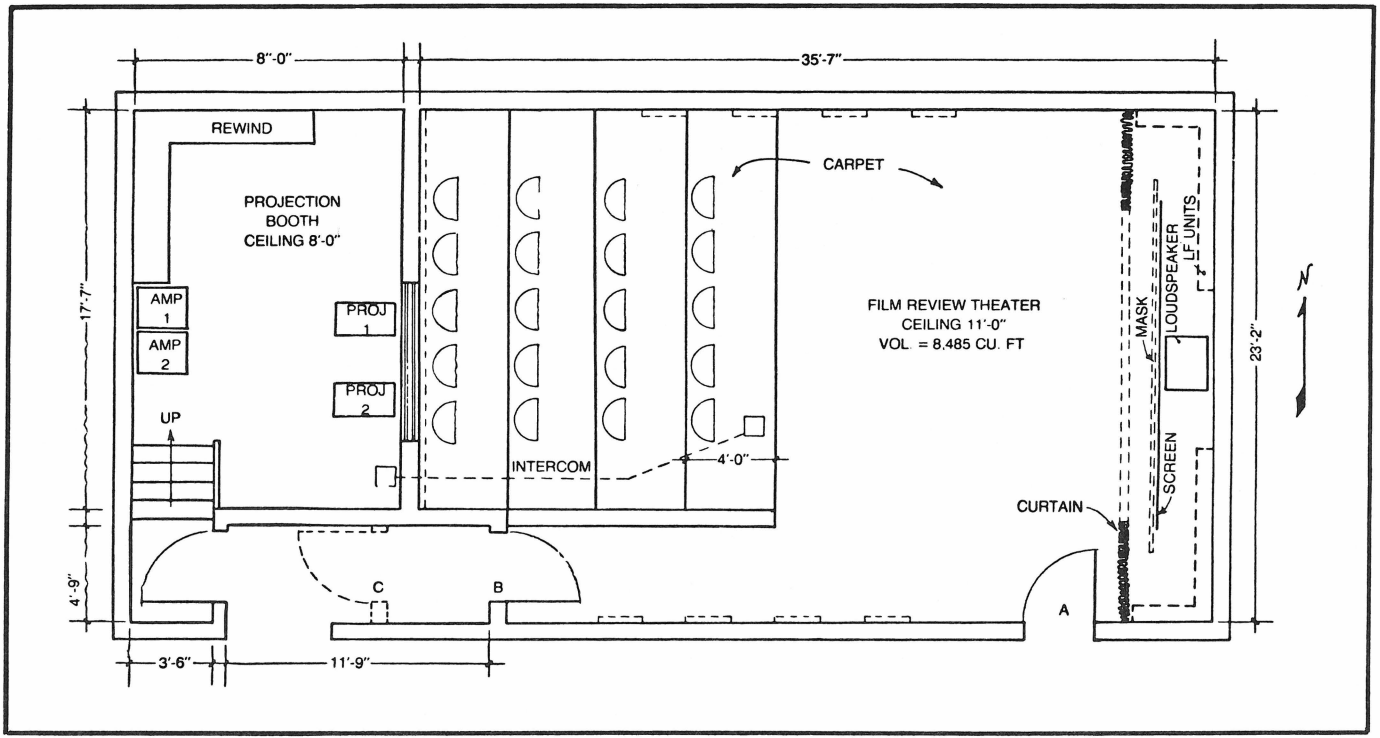


Fig. 13-1. Floor plan of film review theater seating about 20 persons on a stepped riser. Precautions must be exercised to control projector noise and noise from outside as well as distracting light falling on the screen through open door A.

up to 20 people very comfortably, a few more in a pinch. The individual seats may be upholstered, swivel type or simply canvas director's chairs. Arranged on carpeted wood risers of 4 foot width, a feeling of comfort and luxury may be imparted with modest outlay.

DOOR ARRANGEMENT

The background noise level standard adopted for this small theater (the N-25 contour is commonly used, Fig. 2-5) and the environmental noise level outside the theater determine the type of walls required. This has been covered in Chapter 2.

Doors A and B of Fig. 13-1 provide entrance and egress for the screening room. If these are single doors, even though they have a solid core and are well weatherstripped, their insulation against noise from the outside is quite limited. If the external noise is of low level, single doors may be adequate. Adding door C makes a sound lock between doors C and B. This would make little sense unless something similar is done to door A. In addition to the noise, another potential problem associated with door A is that, if opened while the theater is darkened, it may be very disruptive as light from the outside falls on the projected image, disturbing the viewers.

SCREEN

This theater should be equally valuable for projection of 35 mm or 16 mm film prints, or 70 mm or super 8 mm prints for that matter. The same screen can serve them all equally well. Aspect ratio is defined as the ratio of width to height of the film image and the screen proportions are determined by the proportions of the image on the film. Historically, an aspect ratio of four units wide by three units high (1.33:1) has been used.

When sound was introduced to 35 mm film, less room was available for the image of each frame, but a smaller 4 × 3 proportion persisted. Starting with the early introduction of *CinemaScope* and progressing on through many stages, the aspect ratio varied from 2.66:1 on down.

It is now general practice to provide for projection at proportions between 1.33:1 (old 35 mm film and normal 16

mm films) to 1.65 and 1.95:1 for flat, widescreen films and 2.35:1 for anamorphic projection. This means that ample screen area must be provided and that black masks be used to shape the screen to the format to be used, cropping the edges neatly. In Fig. 13-2 a screen 6 feet high and 14 feet wide meets the maximum proportions required, 2.35:1.

The masks are simply black cloth covered frames of light wood or metal. These are arranged as a top and bottom horizontal pair, and a left and right pair for cropping the vertical edges. A fancy (and *very* convenient) installation would have these pairs adjustable by motor drive and remotely controlled from the projection booth so that one button would be pushed for 1.33:1, another for 1.65:1, etc. Other controls for highly professional projection would include motor driven curtains and light dimmers, preferably synchronized.

The screen must be of the perforated type if the loudspeaker is positioned behind it as indicated in Fig. 13-1. The small perforations make the screen essentially transparent to sound in the audible band, yet are not visible at normal viewing distances.

Three types of screens are in common use, distinguished from each other by their surface.

- matte
- beaded
- metallized

A picture projected on a screen having a matte surface appears to have much the same brightness when viewed off to one side as when viewed from directly in front. The general screen brightness level of the matte screen will, however, be quite low. The beaded and metallized screens have a more pronounced directional characteristic, throwing most of the light directly back toward the projector and giving a much dimmer picture off to the side. For quality projection giving a picture of equal brightness over the seating area of the small screening room, a perforated screen with a matte surface is probably the more suitable. It should be mounted in a frame with elastic cord so that its surface is very flat.

PROJECTION BOOTH

The floor of the projection booth is at least 3 feet above the main floor of the screening room so that the projector beam clears the heads of those seated on the top riser. Actually, this beam should not be interrupted by persons walking anywhere in the theater, but with the limited 11 foot ceiling height this ideal could not be attained with the riser plan shown.

The projection room is reached by five steps up from the alcove shared with door B. The projectionist's observation window is 7 feet long and about 18 inches wide and is of customary double glass construction.

Glass in the two projector ports is quite a different problem because of possible color tint and refraction affecting the projected image. From the standpoint of theater noise, however, it is imperative that these small ports be fitted with at least one good thickness of glass. A work table is suggested for film rewinding, etc.

The projection booth should be acoustically treated to reduce the effect of projector noise both in the booth and in the screening room. The surface area of the projection booth is about 691 square feet with an 8 foot ceiling. If the floor is vinyl tile and the walls and ceiling are bare gypsum board the average absorption coefficient might be about 0.05, giving a total absorption of $691 \times 0.05 = 34.55$ sabins at midband.

If the absorption coefficient were increased to 0.30 by the acoustical treatment of room surfaces, the total absorption in the room would be increased to $691 \times 0.30 = 207.3$ sabins. This would result in a decrease in projector noise level of $10 \log 34.55/207.3 = 7.78$ dB. This means that anywhere in the room, except in the immediate vicinity of the projector, the noise level is thus reduced almost 8 dB by the introduction of the absorbing material. This would make it much more comfortable for the projectionist and would reduce projector noise in the screening room as well.

Fire regulations pertaining to projection rooms must be determined before actual construction and acoustical treatment are begun, but acoustically the only requirement is to make the room as highly absorbent as feasible over the audible frequency range with no worry about uniformity.

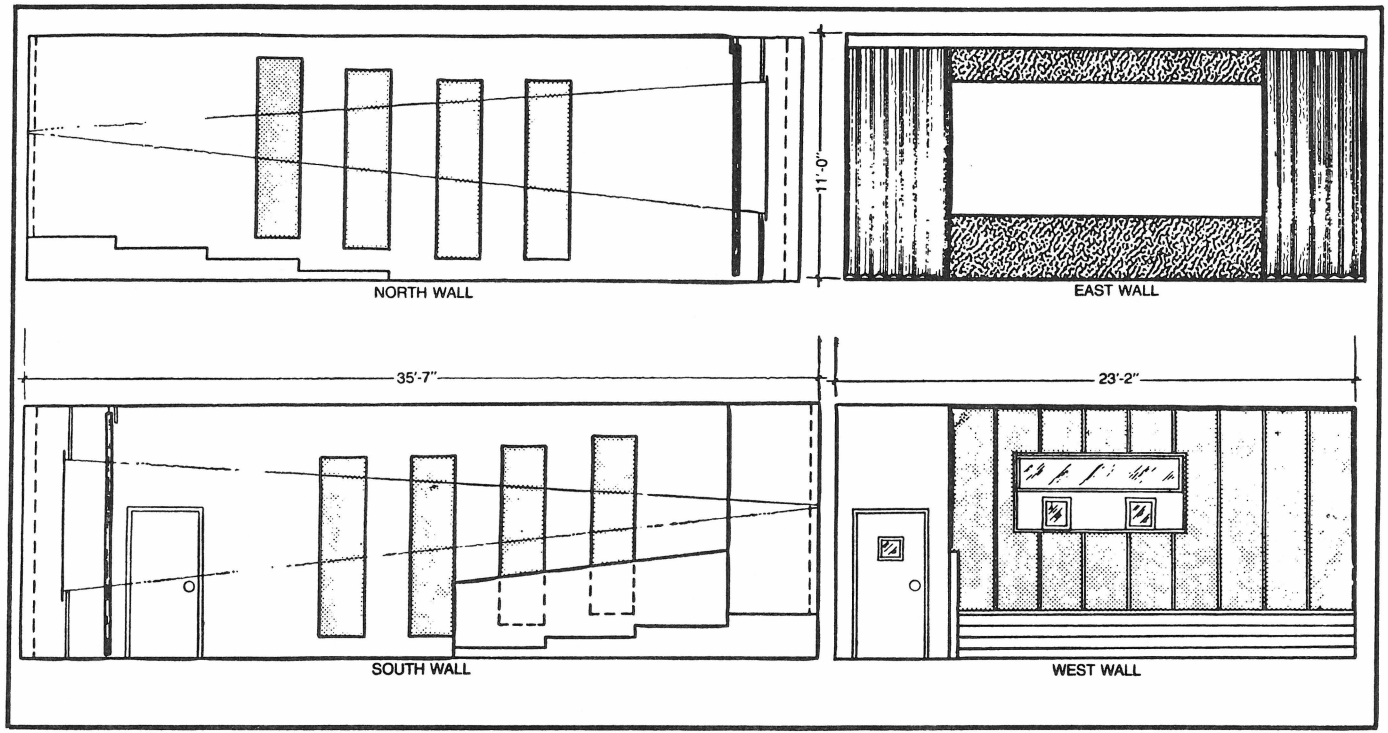


Fig. 13-2. Wall elevations showing placement of screen and its associated elements as well as acoustical treatment. The rear wall and side wall panels are basically 4 inches of 703 glass fiber covered with a perforated vinyl fabric.

Another detail which can contribute to smooth operation of the projection booth is some form of intercommunication with a control seat in the audience area. This link provides a professional touch to a projection event in such things as when to roll it, the adjustment of sound level, etc.

THEATER TREATMENT

A film review theater of this type is basically a listening room and should be acoustically treated as such. There is the question of whether speech or music should be favored, but the understanding of narration and dialog is taken as the more fundamental requirement. For a room of 8,485 cubic foot volume, the optimum reverberation time for speech is close to 0.5 second. We shall take 0.5 second as our goal, uniform 125 Hz-4 kHz, but recognizing in advance that tolerances are not as tight for film viewing as they would be for recording studios or critical monitoring rooms.

The entire floor area of the film review theater, including the riser seating area, is carpeted with a heavy carpet and pad as indicated in Table 13-1. This is in deference to the comfort and enjoyment of guests and in spite of the acoustical compensation required.

Another component of acoustical absorption having characteristics similar to carpet is the curtain. For this the area entered in the computation is that which the curtains offer when retracted to reveal the 14 foot width of screen (the 2.35:1 aspect ratio). The question arises, "should both sides of the partially retracted curtain be considered as active abosorber?" This depends on how the curtain was placed when the coefficients were measured. The book[35] says, "Medium velour, 14 ounces per square yard draped to half area."

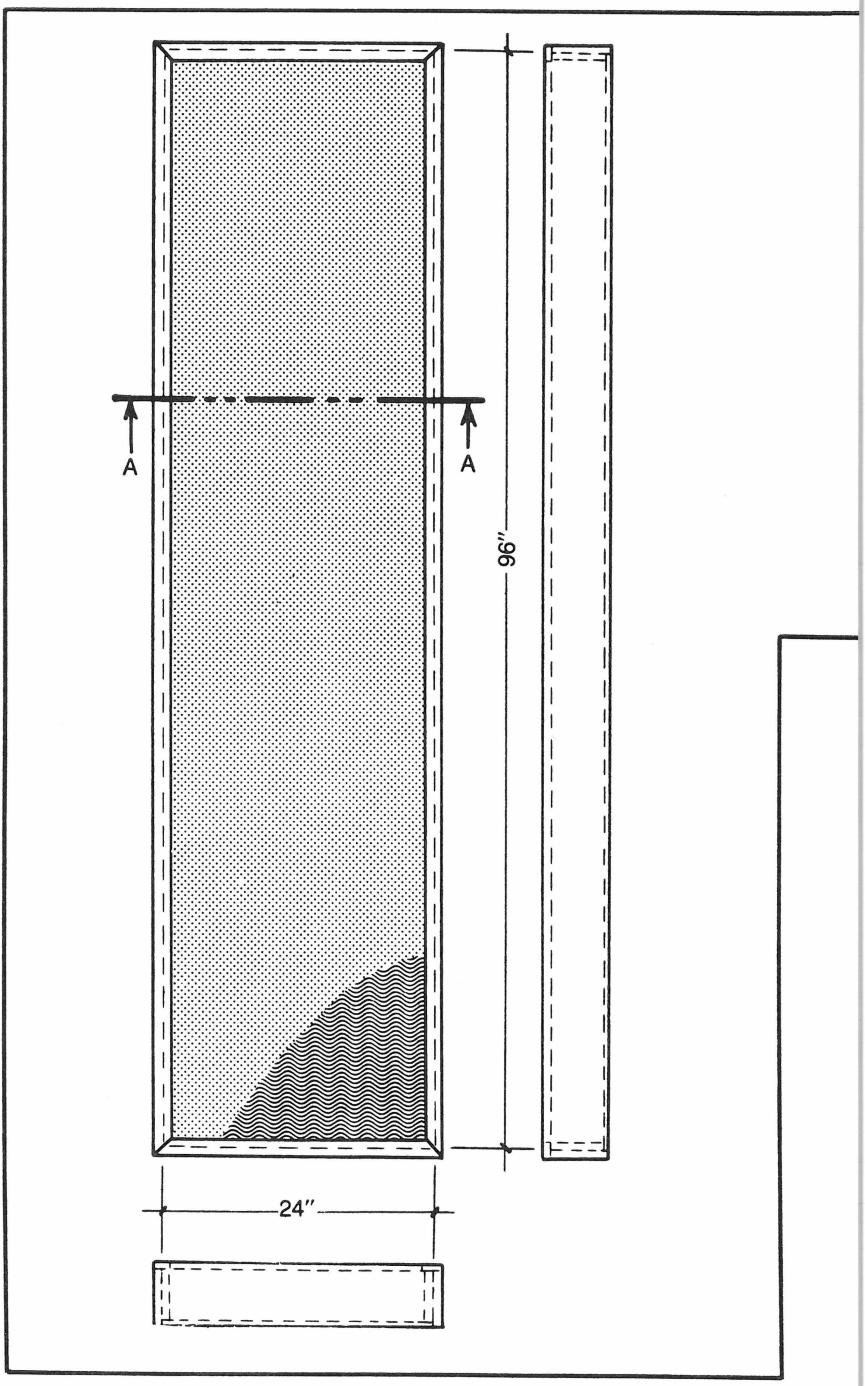
Although the inference is that the drape is not far from a wall (ours are about 3 feet from a wall), the area of only one side of the curtain has been entered in Table 13-1 and the possible error of a few dozen sabins registered in the inner consciousness.

Wideband absorption, again with 4 inches of Owens-Corning 703 Fiberglass as the basic dissipative element, is

Table 13-1. Film Review Theater Calculations

Size ..... 23'-2" × 35'-7", ceiling 11'-0"
FLOOR & RISERS ..... Heavy carpet and pad
WALLS ..... Side walls. 8 wideband panels 2'-8' 4" 703 covered with perforated vinyl fabric (Fig 13-3)
Rear: 4" 703, perforated vinyl cover (Fig. 13-4)
Behind screen Low Peak absorbers in corners, 0.31% perf., 8" deep, 4" 703 (Fig. 13-5, 6)
SURFACE AREA ..... 2,901 sq. ft.
VOLUME ..... 8,485 cu. ft.

MATERIAL	S Area Sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	841	0.05	42.1	0.15	126.2	0.30	252.3	0 40	336 4	0.50	420.5	0 60	504 6
Curtain, open	100	0.07	7.0	0.31	31.0	0.49	49 0	0.75	75 0	0 70	70.0	0.60	60 0
Wideband panels 8 at 14.8 sq. ft.	119	0.99	118.0	0.99	118.0	0.99	118.0	0.99	118.0	0.99	118.0	0 99	118.0
Wideband, east wall	120	0.99	119.0	0.99	119.0	0 99	119.0	0.99	119 0	0 99	119.0	0 99	119.0
Riser, ¾" ply	324	0.38	123.1	0.19	61.6	0.06	19 4	0 05	16.2	0 04	13.0	0 04	13 0
Gypsum bd. ½"	1660	0.10	166.0	0.05	83.0	0.04	66 4	0 03	49.8	0 03	49 8	0 03	49 8
Low Peak	190	1.0	190.0	0.83	157.7	0.44	83.6	0.29	55.1	0 24	45 6	0.20	38 0
Total sabins, Sa		765.2		696.5		707 7		769.5		835 9		902 4	
Ave. Absorp. Coeff., a		0.263		0.240		0.244		0 265		0.288		0 311	
Reverb. Time, Sec.		0.47		0.52		0.51		0.47		0.42		0 38	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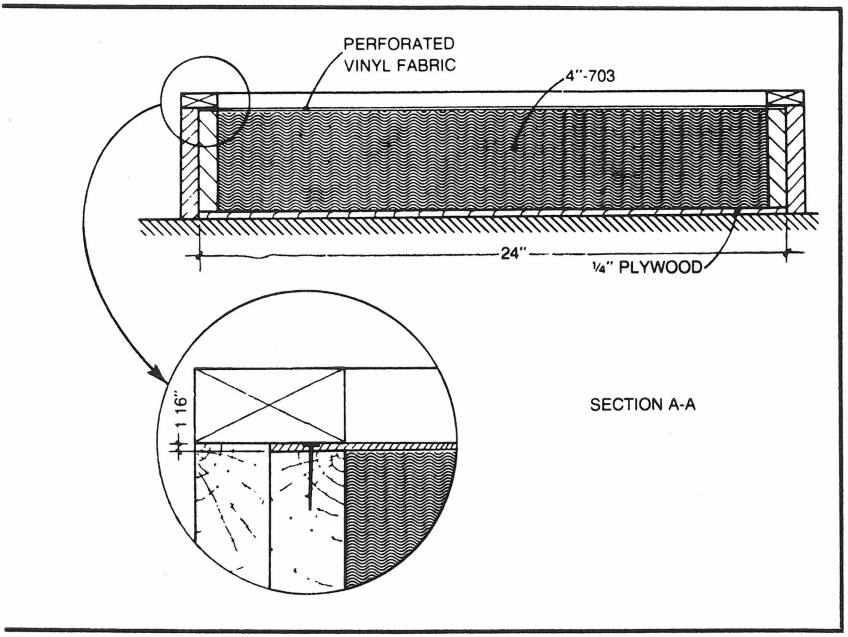


Fig. 13-3. Constructional details of 2 foot × 8 foot wall absorbing panels covered with vinyl fabric. The frame and spacer width must be adjusted to accommodate the 4 inch semi-rigid glass fiber board without bulging of vinyl cover.

applied to the north and south walls in the form of 2 foot × 8 foot wall panels and to the entire rear (west) wall. In both cases the 703 is covered with a decorative vinyl fabric perforated for a reasonable degree of sound transparency. The vinyl fabric supplied by L.E. Carpenter and Company, (L.E. Carpenter and Co., 171 North Main Street, Wharton, New Jersey 07885. Telephone (201) 366-2020), called *Vicrtex*, comes in many attractive patterns and colors, but is perforated at the factory only on order. The perforation percentage of the Vicrtex is estimated to be between 12 percent and 15 percent. This vinyl covering can be a main contributor to the decor of the room if carefully chosen.

The wideband wall panels are located as shown in Fig. 13-2, four to each side wall and positioned so that a panel on one wall faces bare wall between panels on the opposite wall. This should provide reasonable control of flutter echoes in the north-south mode, even as the carpet does for the vertical mode.

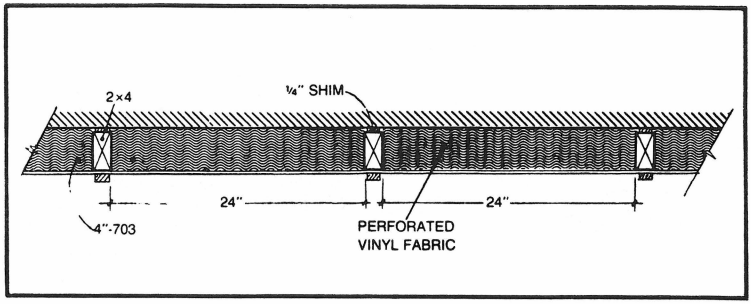


Fig. 13-4. Detail of rear (west) wall treatment. The 2 × 4 frame is shimmed out about ¼ inch to avoid bulging of perforated vinyl fabric face by the glass fiber board.

Figure 13-3 gives necessary details of construction of the wall panels. The perforated vinyl fabric comes in a 54 inch width which will provide for two 24 inch panels. If desired, 1 × 6 lumber could be used for the external frame which would result in an air space between the 703 and the back board. This would increase low frequency absorption.

Figure 13-4 shows how the rear (west) wall is framed with 2 × 4s making spaces 24 inches wide to accommodate both the 24 inch width of the 703 and the 54 inch width of Vicrtex cover. The 2 × 4s are only about 3-¾ inches and by shimming them out from the wall about ¼ inch the 703 will not tend to bulge the Vicrtex. A finish strip is nailed to each 2 × 4, covering the Vicrtex edges and overlap.

Low frequency absorption is required to compensate for low frequency deficiencies of carpet and curtains. The risers, constructed of ¾ inch plywood on a wood frame, contribute a significant amount of absorption, peaking about 125 Hz. In addition, the gypsum plaster board on walls and ceiling not covered by other elements also absorbs well at low frequencies.

In Table 13-1 gypsum board of ½ inch thickness has been assumed, although relatively small changes would be expected if it were ⅝ inch or even double thickness.

As the riser and wall/ceiling surfaces do not give quite enough low frequency compensation, some perforated panel Helmholtz resonators are introduced to the room. These are not the most beautiful things in the world, hence they are hidden behind curtains and screen. By placing them in the

corners, they will contribute to absorption in both the N-S and E-W modes and leave space for the loudspeaker as well. Also, it is recalled that all room modes terminate in the corners.

The positions of these Helmhotz resonators are shown in Fig. 13-5 and their construction is detailed in Fig. 13-6. The 3/16 inch diameter holes on a square pattern 3 inches on centers turns out to be a perforation percentage of about 0.31 percent.

Other configurations of hole diameter and spacing yielding perforation percentages of about 0.31 percent ± 10 percent are acceptable. Care should be exercised to assure that supporting 2 × 8s and dividing 1 × 8s fall between rows of holes. The 3/16 inch Masonite sheets can be stacked for drilling to facilitate this chore.

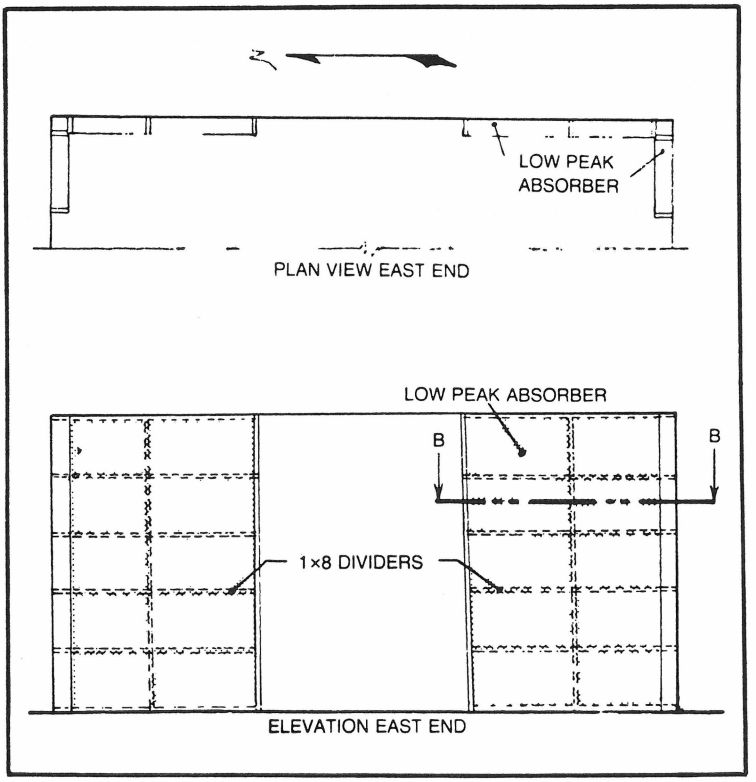


Fig. 13-5. Behind the screen on the east wall is located a low peak absorber in each corner, floor to ceiling. Dividers of 1 × 8 lumber break up the air space to discourage modes of vibration parallel to the face of the absorber.

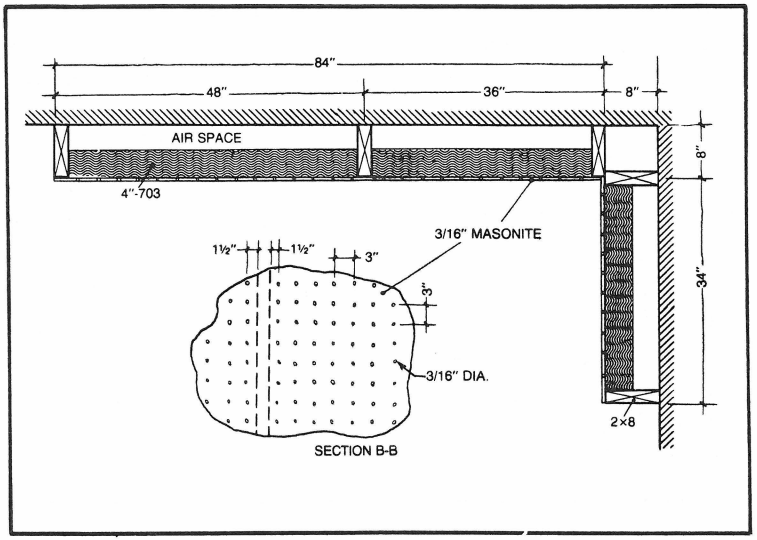


Fig. 13-6. Section B-B from Fig. 13-5 of a typical low peak corner absorber behind the screen. The perforation percentage is about 0.31 percent.

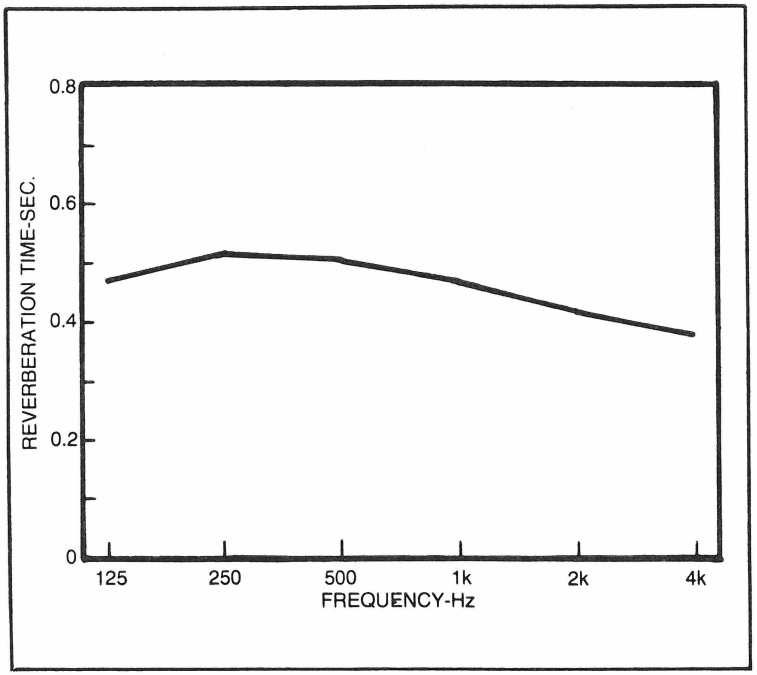


Fig. 13-7. Calculated reverberation time of film review theater. This characteristic is satisfactory for this room which is considered primarily as a listening room for speech.

REVERBERATION TIME

Following through on the calculations of Table 13-1 the reverberation time at each of the six frequencies is determined. The values from the table are plotted in Fig. 13-7. This graph droops somewhat above 500 Hz from the desired 0.5 second. However, as previously stated, the listening conditions should not be noticeably affected because of this.

What should be done to improve this if measurements confirm Fig. 13-7? It is obvious that the lower reverberation times at the higher frequencies are the result of too much absorption of carpet and curtain. To correct this, more low frequency compensation could be introduced to flatten the curve at about 0.4 second and then wideband absorption removed to lift the whole curve to 0.5 second.

Chapter 14
Multiple Studios

Features: Splaying of walls, space saving in studio suites, proprietary wall panels, sand for noise insulation, floating floors.

All the good things should be maximized, all the bad things minimized. This message is repeated frequently enough to encourage maximum recall with minimum effort. A new building was to be built, but many activities were in competition for the maximum space a minimum budget would allow.

As for recording studios, talk at first swung toward a large number of very small studios. This was parried by solid information on the adverse effect of small studio spaces on sound quality and it was agreed to reduce the number of studios so that at least the 1500 cubic foot minimum volume could be realized. Most of the work is the recording of voice programs, but numerous languages are involved, necessitating a multiplicity of studio-control room suites.

It is desirable to make all these suites very similar so that language teams can go from one to another with no delay or inconvenience caused by lack of familiarity. Essentially identical acoustics of all speech studios would also allow complete freedom in intercutting.

Music recording of fairly large vocal and instrumental groups requires one music recording studio, but this larger

studio must also be capable of being pressed into service for voice recording at times. This is a very challenging and interesting set of requirements, the solution of which poses some technical problems of general interest.

Heretofore in this book splayed walls have been conspicuous by their scarcity. One reason for this is that many of the studios studied here were located in existing buildings. In such cases splaying of walls requires either reconstruction of great sections of the building or losing precious studio volume, or both. This is costly financially and acoustically. Splayed walls do reduce the chance of flutter echoes being produced, even as well distributed absorbing materials do. In a new building, however, splaying represents little or no additional cost and no loss of room volume. Under such conditions it is most logical to include it.

TYPICAL RECORDING SUITE

Figure 14-1 represents a typical speech studio-control room suite having:

- Rooms of minimum volume (about 1500 cubic feet).
- Two splayed walls in each room.
- Sound lock space shared by two or more suites.
- An equipment storage space for each two suites.

This is certainly maximizing function in limited space as two speech studios, their associated control rooms, an adequate sound lock and a shared storeroom are obtained in a rectangular area about 17 feet × 24 feet with a ceiling height of 10 feet. The plan of the single recording suite of Fig. 14-1 thus becomes an elemental building block of the larger studio complex. This sets the pattern for all control rooms and all speech studios, in fact, everything but the music studio.

SPLAYING PLAN

Normally walls are splayed 1:10 or 1:5. Ratios in this form are readily understood by construction workers but they can also be expressed in degrees (5.7 degrees or 11.3 degrees) by plugging 0.1 or 0.2 into the trusty calculator and punching *Arc-Tan*. Due to a trigonometric and a love of round figures an even angle of 5 degrees was adopted for

the splay of these studio walls which was later realized to be a very odd ratio for the construction people, 2⅛:24.

The scheme of splaying of all speech studios and control rooms is illustrated graphically in Fig. 14-2. The two walls to be splayed are simply rotated 5 degrees about their midpoint. As two walls are involved, and each wall can be rotated clockwise or counterclockwise about its midpoint, there are four possible combinations of room shape with the 90 degree corner held in the same position. This 90 degree corner can be placed in other positions by rotating or flopping the sketches. Three of these four possibilities account for all the room shapes to be included.

The larger music studio splaying plan is shown in Fig. 14-3. Actually, it is the plan of Fig. 14-2A adapted to the different proportions and dimensions of the music studio, Studio C. It should be emphasized at this point that the four splaying plans of Fig. 14-2 have somewhat different areas, even though based upon identical rectangles. It should also be remembered that only the N-S and E-W modes are touched with the above wall splays. The vertical flutter echo must be cared for in some other way.

ROOM PROPORTIONS

To a first approximation the dimensions of the basic rectangle from which the splay pattern is derived may be used to establish proportions for the best distribution of axial modes. The actual modal frequencies would, of course, differ slightly from these. One way of looking at it (Fig. 14-3) would be that the sound energy reflected to a splayed wall from an opposing, but unsplayed, wall would not return to the same spot on the originating wall, a_1, but would return to a_2, a_3, etc. It would "walk the slope" and tend toward becoming a tangential mode.

Another approach would be to consider dimension d_1 to give one axial mode frequency and dimension d_2 another one slightly lower. Both outlooks are based on geometrical acoustics which fail miserably in the low frequency region giving us the most trouble. It is really a very complex problem and the mathematical tool of wave acoustics is a more powerful ap-

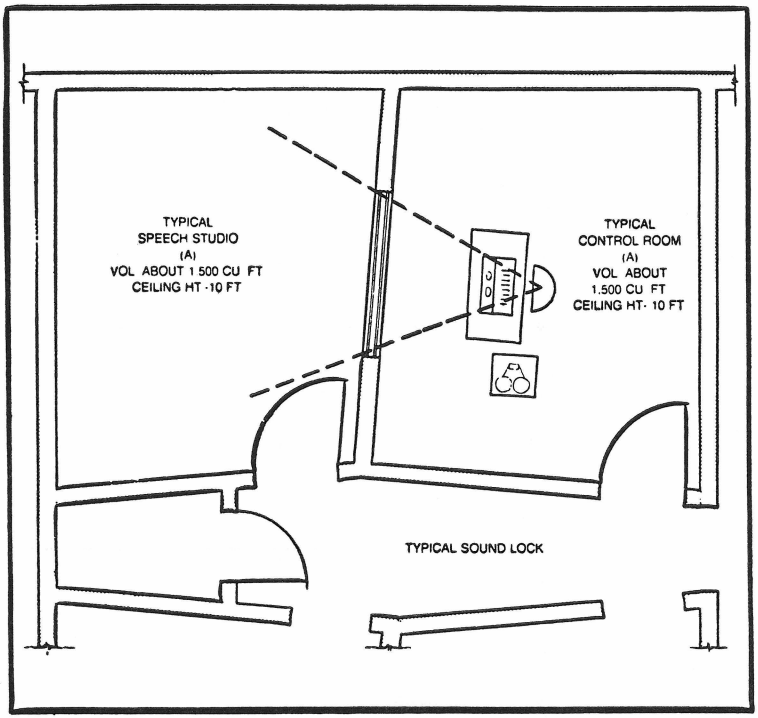
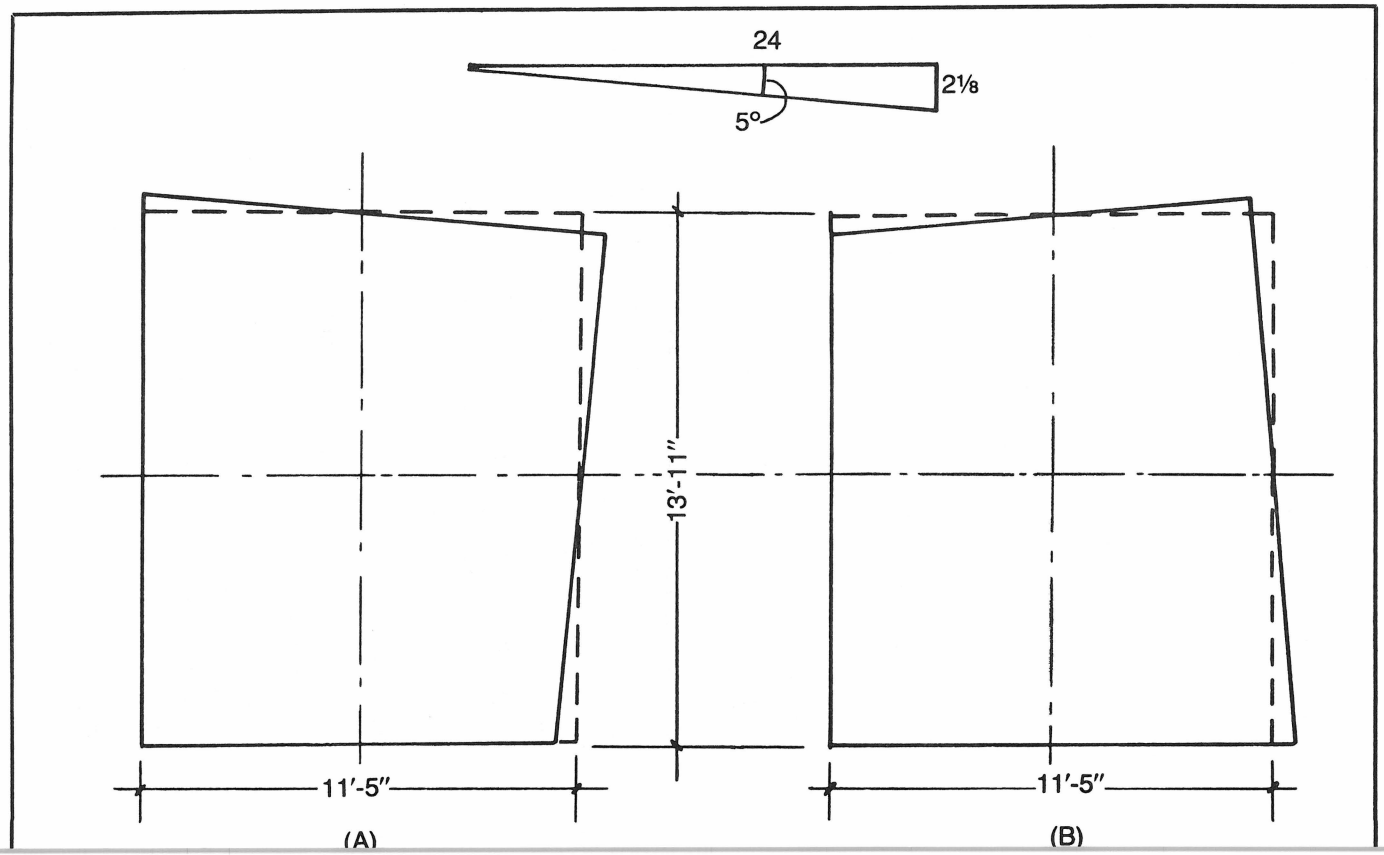


Fig. 14-1. Typical speech recording suite featuring rooms of about 1,500 cubic feet volume and splayed walls coordinated with a sound lock corridor. This is the basic unit of which the larger studio complex is composed.

proach. Although it is only an approximation, establishing favorable room proportions according to the basic pre-splaying rectangle is a logical and practical approach and the only simple alternative.

FLOOR PLAN

Using the typical speech studio-control room layout of Fig. 14-1 and the splaying plans of Figs. 14-2 and 14-3, the floor plan of Fig. 14-4 has been derived. It includes three speech studio suites, A, B and D, and one music studio, Studio C, with its control room. Control Room C, serving the music studio, is comparable to the other smaller rooms. One sound lock corridor serves three studios and three control rooms. Were it not for the stair well, all eight rooms might well have been served by a single sound lock. These studios are located in one corner of the top floor of the two-story building.


24
2⅛
5°
13′-11″
11′-5″
11′-5″
(A)
(B)

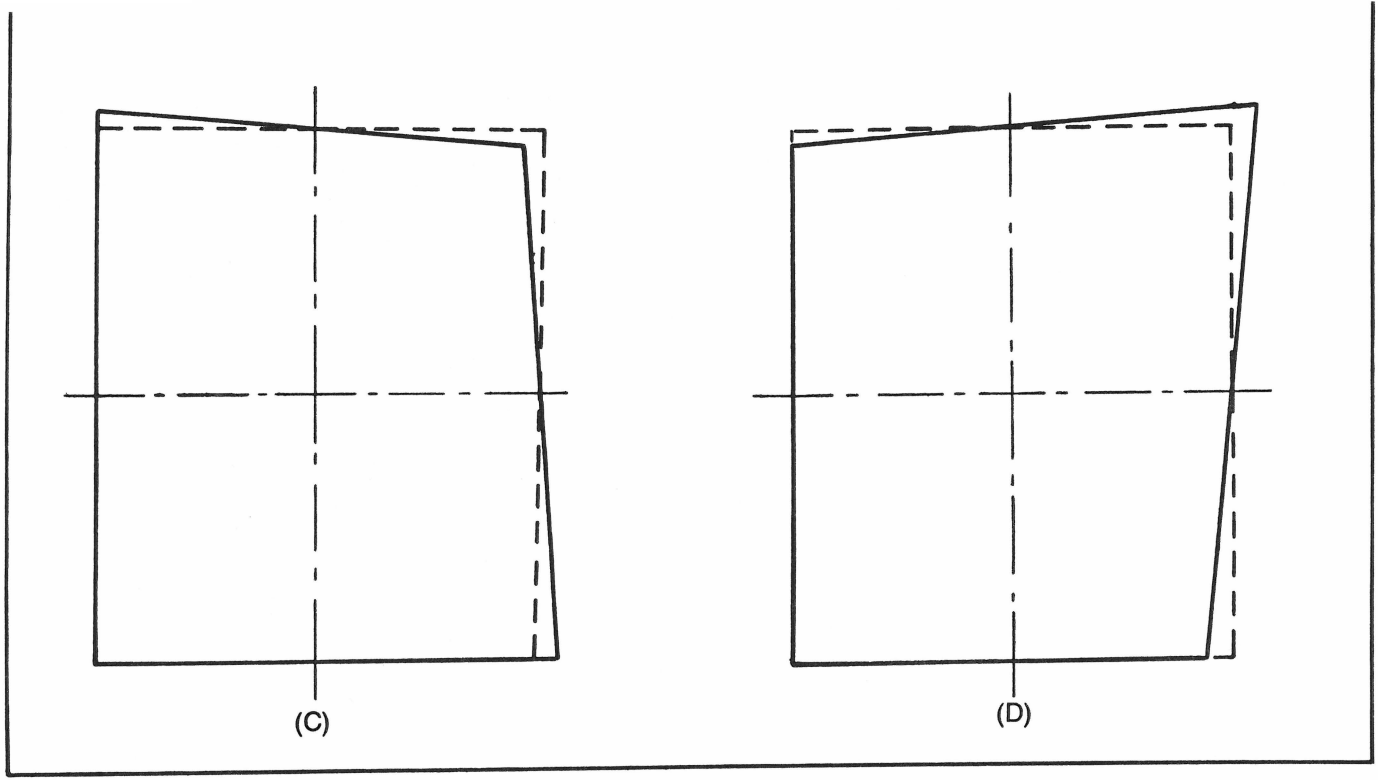


Fig. 14-2. Splaying plan for the speech recording studios and associated control rooms. The two walls to be splayed in each room are rotated 5 degrees about their midpoints.

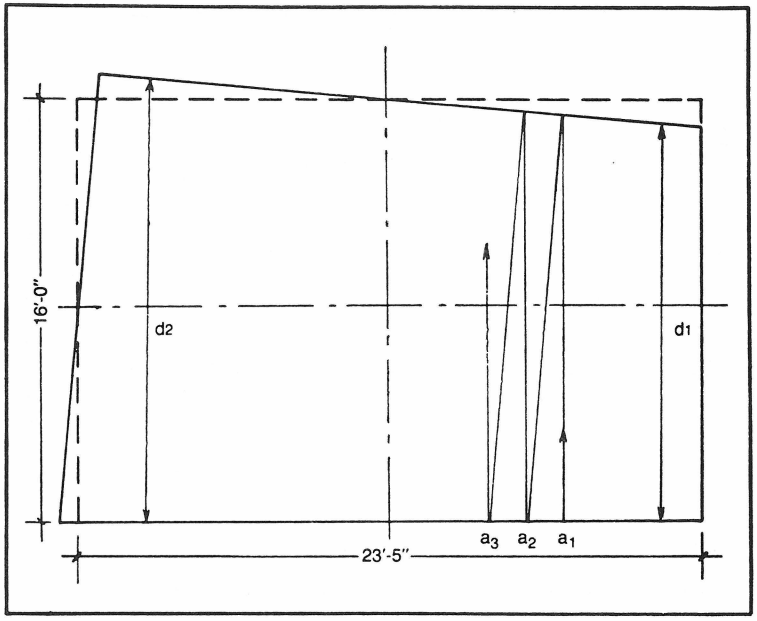


Fig. 14-3. Splaying plan for the larger music recording studio is also based on 5 degree rotation about the midpoint of each of the two walls.

TRAFFIC NOISE

As the building housing the studios is on a well travelled boulevard in a major city, traffic noise must be considered. Traffic noise varies greatly with the time of day and the only way to evaluate it properly is to run at least a 24 hour noise survey on the proposed site. Obviously, there is less traffic at night and noise conditions are at their lowest point in the early morning hours, but the 24 hour survey makes possible such statements as "The noise level exceeds 75 dB(A) only 4 percent of the time." This is the sort of data required to support various types of decisions.

This ideal approach was not possible in this instance, therefore an octave analysis of peak boulevard traffic noise was made at the curb closest to the building site with the results shown in Fig. 14-5. This was done before the exact location of the building was known. Once the building location was set, the measured values at the curb were extrapolated to the nearest face of the building by assuming spherical divergence of sound with its resulting 6 dB reduction with each

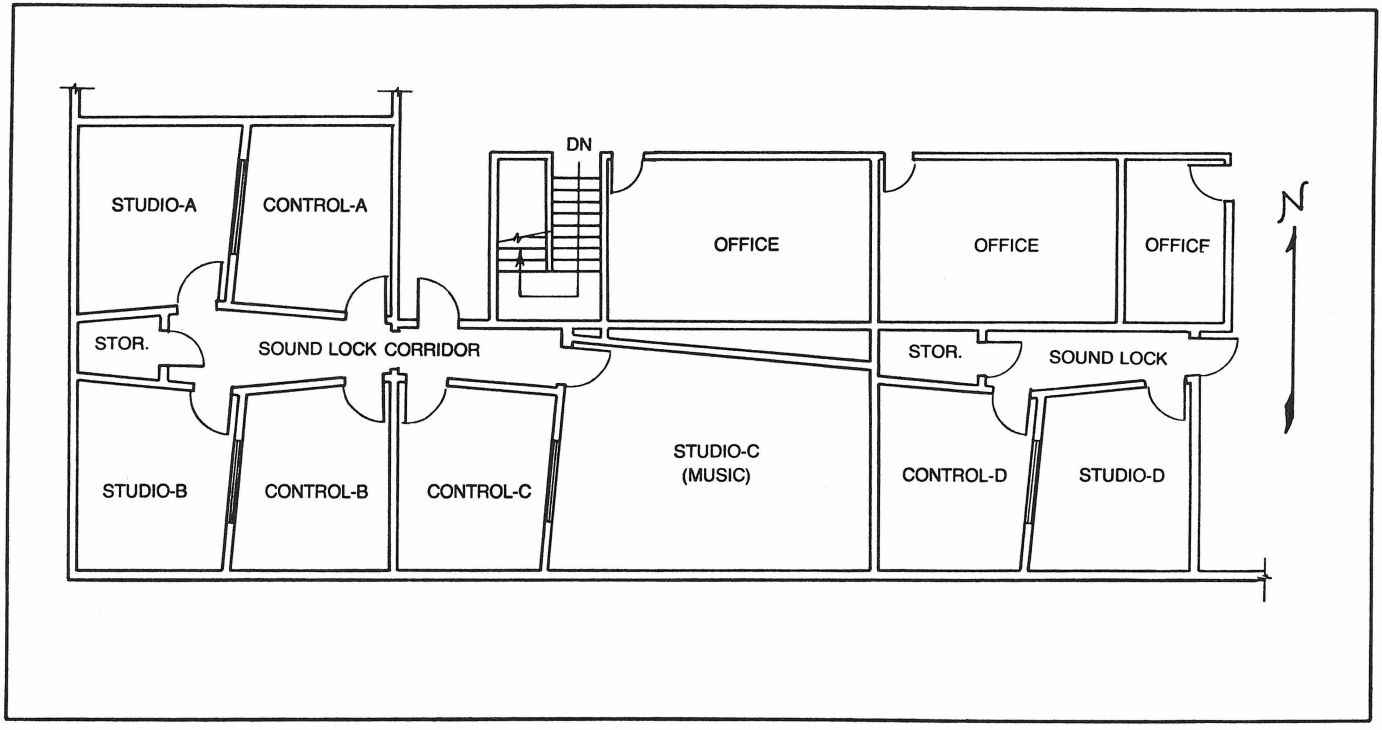


Fig. 14-4. Floor plan incorporating three speech recording suites such as shown in Fig. 14-1 and a larger music recording studio. The control room for the music studio (Control Room C) is comparable to the speech studios and their control rooms.

doubling of the distance from the line of traffic. This procedure yielded the broken line spectrum of Fig. 14-5, the estimated noise spectrum just outside the building.

The N-15 contour is our goal for noise level within studios and control rooms which, of course, could very well have noise contributions from other activity within the building, air-conditioning equipment, etc., in addition to traffic noise. At the moment, however, only traffic noise is under consideration.

Special urging resulted in the placement of the studio corner of the building on the side away from the boulevard. This offers some protection from traffic noise. The building code requires ventilation of the attic space above the studio area which means that traffic noise of considerable magnitude pervades the attic space immediately above the studio ceilings.

With the wall construction to be described later, the greatest prospect for a traffic noise problem in the studios turns out to be via this ceiling path. If sound level measurements within the studios reveal traffic noise levels appreciably above the N-15 contour, a layer of sand will be added between the ceiling joists above the double drywall ceiling. A 1 inch layer of sand would "beef up" the ceiling, acoustically speaking, 36 dB at 500 Hz on a mass basis and would weigh only about 8 pounds per square foot. Each doubling of the sand thickness would add 3 dB transmission loss, but would double the weight.

It is advisable to stop short of a thickness at which sand would break through the ceiling and pour down on unsuspecting personnel below. A modest amount of sand could add very substantially to the insulation strength of the ceiling against external noise.

EXTERNAL WALLS

There is information in Fig. 14-5 which helps in deciding how heavy to make the external walls of the studio. The distance between the N-15 contour and the broken line graph represents the minimum transmission loss the walls must provide. This loss requirement varies with frequency. It is maximum at about 1 kHz, decreasing for both lower and higher frequencies.

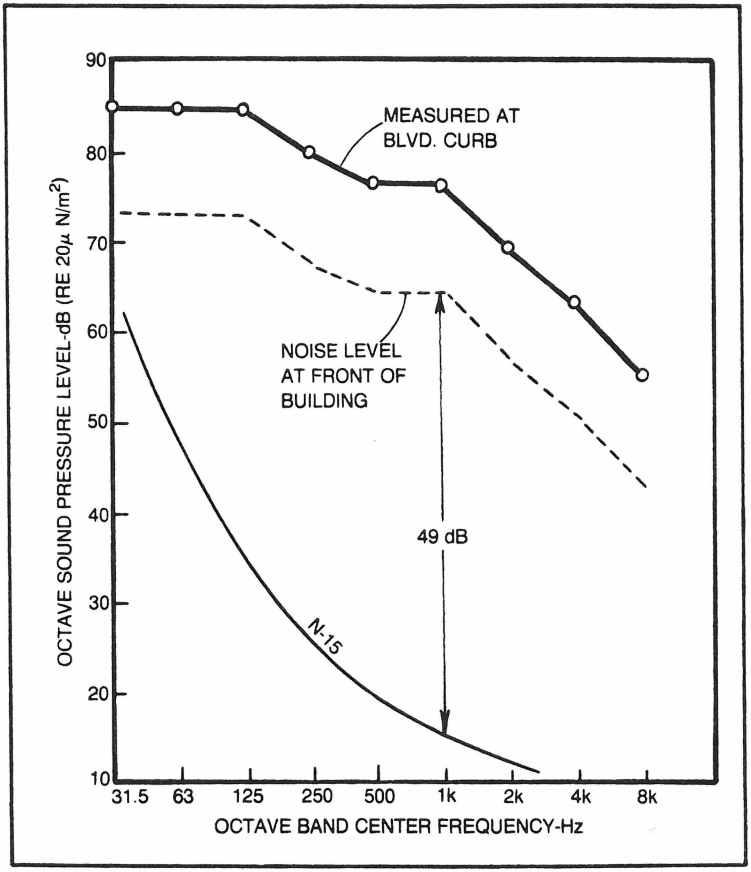


Fig. 14-5. Traffic noise peaks were measured at the boulevard curb and later (when the building position was established) extrapolated to the face of the building. The N-15 contour is the goal for noise within the studio. The difference between these two graphs is the transmission loss the studio external walls must provide.

This is unfortunate in one sense because the sensitivity of human ears is greatest in this general frequency region.

It is fortunate in another sense because walls of common materials and normal construction can offer quite good transmission loss at 1 kHz, much greater than at much lower frequencies. The octave noise level of 64 dB at the face of the building is 49 dB higher than the N-15 contour at 1 kHz which we are striving for within the studio.

The external wall construction of Fig. 14-6 was considered to be adequate to provide this much transmission loss,

especially knowing that the 64 dB applies to the front face of the building and the external walls of the studios are in the rear. The lower part of the wall of Fig. 14-6 is the top of the tilt-up panels. The upper part of frame construction is plastered outside and covered with double 5/8 inch gypsum drywall panels inside. The insulation between wall studs serves the double purpose of thermal insulation and discouraging acoustical resonances in the cavity which degrade the effectiveness of the wall in attenuating external noise.

The ceiling construction is similar, except for the plaster. Should sand be added to the upper surface of the ceiling drywall at a later time, the insulation would first be removed, the sand applied and then the insulation would be replaced on top of the sand.

INTERNAL WALLS

The construction of typical internal walls is specified in Fig. 14-7. Double layers of 5/8 inch gypsum board are standard on every wall or ceiling separating sound sensitive areas from outside noise. The gypsum panels of all studio walls (except external) are not nailed to the studs but are supported resiliently. The base layer board is secured to the resilient channels with screws. These resilient channels, U.S. Gypsum RC-1 or equal, are first nailed horizontally to the studs, spaced 24 inches.

The vertical base layer board is then secured to the resilient channels with special screws of proper length so that the flexible action of the channel is not destroyed by screws hitting studs. The face layer of gypsum board is then applied horizontally with adhesive. All joints are then finished in the normal way.

Figure 14-8 illustrates the preferred method of staggering layers of gypsum board at corner intersections. The entire periphery of the base layer should be carefully caulked with non-hardening acoustical sealant. Such efforts toward hermetically sealing each room pays great dividends in reducing sound leaks and assuring maximum transmission loss of the wall. The resilient studio face of a wall resonates at a different frequency than the opposite nailed face.

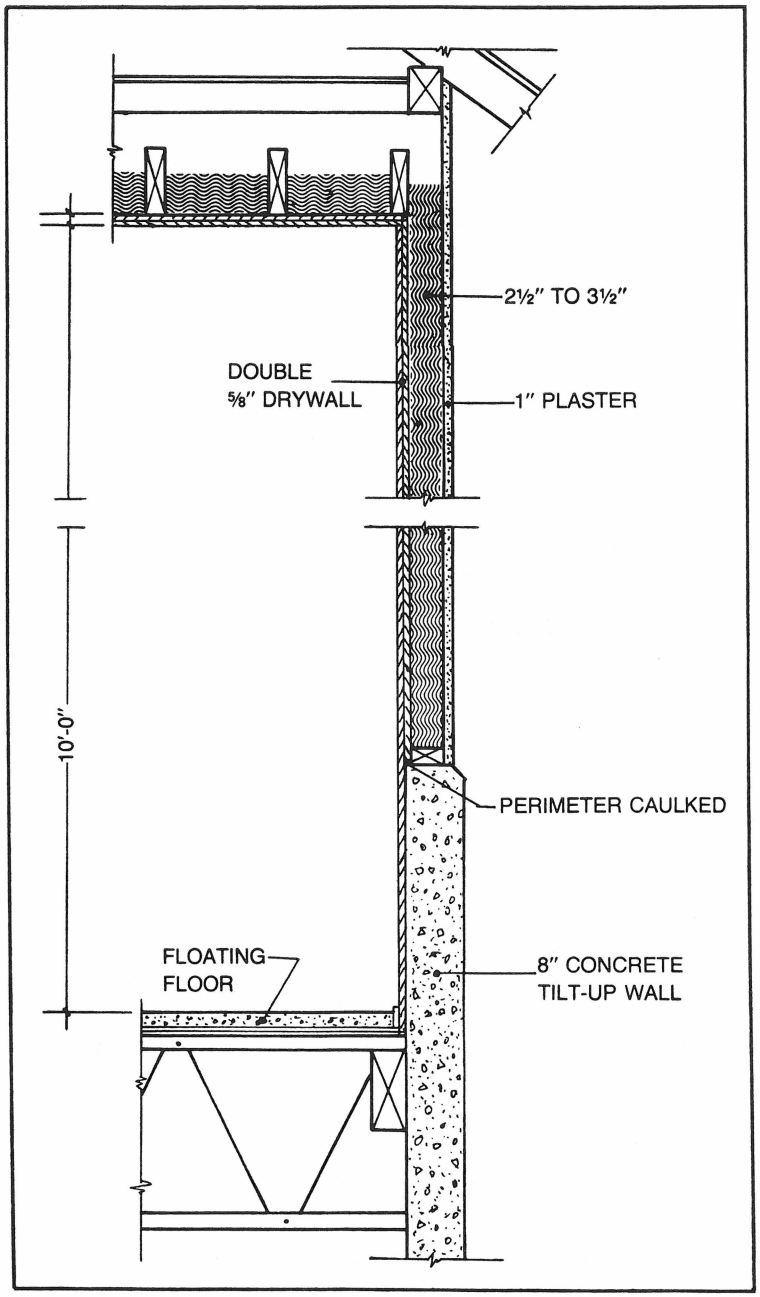


Fig. 14-6. Plan of external wall of studios and control rooms. Tight sealing of the base layer of gypsum board around its periphery contributes significantly to wall performance in protection of studios against external nosise.

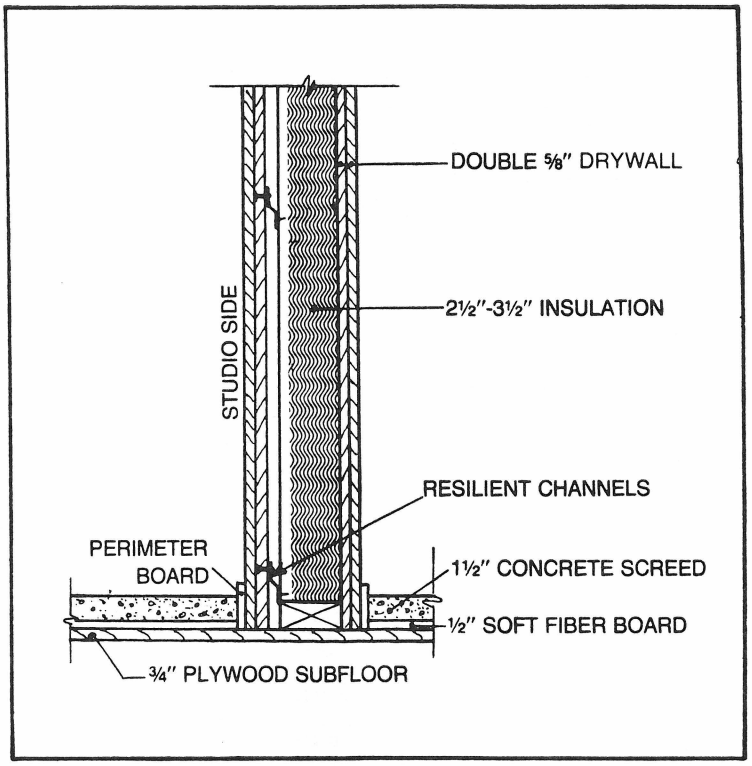


Fig. 14-7. Plan of interior walls of studios and control rooms. On the studio side the base layer of gypsum board is screwed to resilient channels and the face layer is cemented to the base layer. Such a resilient mounting makes the resonance frequency of the wall diaphragm on the studio side different from that of nailed panels on the other side, preventing coincidence and thus improving transmission loss of the wall.

Such resonance effects tend to reduce transmission loss at the resonance frequency and different handling of the two wall faces displaces one resonance point from the other, improving overall wall performance.

FLOATING FLOOR

To obtain sufficient protection against noise of other activities in ground floor rooms below the studio area, a floating concrete floor was required in studios and control rooms. There are available numerous fancy mechanical ways of supporting floating floors on springs and rubber devices as well as proprietary impregnated glass fiber boards and strips

which are excellent in floating floors, but expensive. An inexpensive method used in Germany a quarter of a century ago was pressed into service.[37]

A soft fiber board is layed on the structural floor as a support for the concrete. The stiffness of the fiber board is reduced by coating the underside of it with cork granules before laying it on the structural floor. The fiber board is then covered with plastic sheets and overlapped at least 3 inches. It also runs up over the perimeter board indicated in Fig. 14-7. The concrete screed is thus prevented from running into cracks between fiber boards which would form solid bridges between the structural floor and the floating floor, destroying the floating characteristics. The cork granules are said to improve the impact sound insulation about 16 dB over the fiber board alone. The 1½ inch concrete thickness is certainly minimum.

To reinforce such a floor, which is a very good precaution, the thickness of the concrete must be 3 inches to 4 inches. In thinner layers it is almost impossible to keep the reinforcing screen in the center of the concrete layer during the pouring. If the reinforcing wires are on the bottom of the layer, little reinforcing results. The danger is that concentrated loads, such as the legs of a grand piano, may crack the concrete, reducing its sound insulating value.

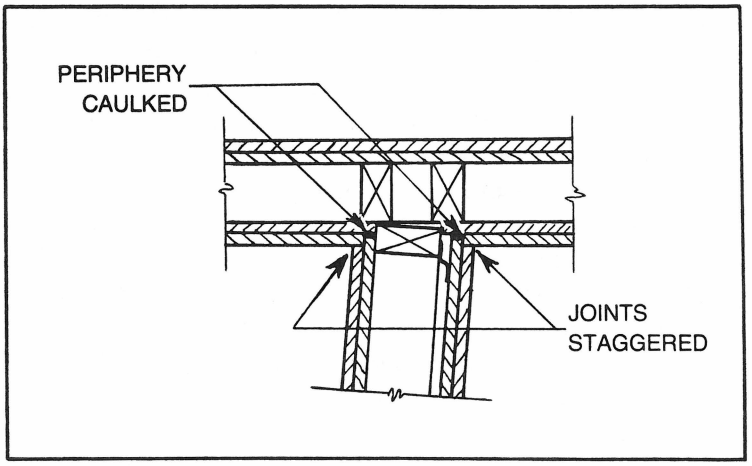


Fig. 14-8. Plan for staggering gypsum layers at corner joints to reduce noise leaks.

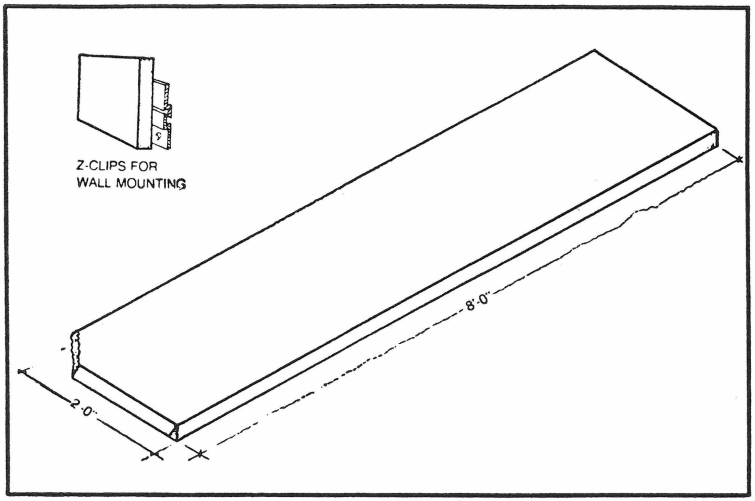


Fig. 14-9. The panels selected for use in all studios and control rooms are 2 foot × 8 foot Vicracoustic panels composed of 2 inches of dense glass fiber covered with an attractive perforated vinyl fabric. Mounting to walls is by use of Z-clips.

TREATMENT OF STUDIO A

The specification of carpet for all studios dominates their acoustical treatment. The drywall wall and ceiling surfaces provide a modest, but insufficient, amount of low frequency compensation for the carpet. Helmholtz type resonators can easily supply the remainder of compensation required, but the problem is, where to put them? Thick boxes on the walls and ceilings are not an esthetic delight. It was decided to use a frame suspended from the ceiling to hold the low frequency boxes and illumination fixtures and to shield both from view with a lower frame face of plastic louver panels of either eggcrate or honeycomb type openings.

Should the usual panels of 4 inches of 703 Fiberglas adorn the walls? In the interests of appearance it was decided to employ proprietary panels of glass fiber covered with decorative, perforated vinyl wallcovering manufactured by L. E. Carpenter and Company. *Vicracoustic panels* 2 feet × 8 feet × 2 inches were selected. The core of semi-rigid glass fiber, which does the absorbing, can be covered on one or both sides with ⅛ inch high density glass fiber substrate if required for protection against impact.

In this studio application the less expensive Type 80 panel, which consists only of the absorbing core wrapped on face and edges with perforated vinyl, was considered adequate. Panels (Fig. 14-9) are mounted on the walls by the use of Z-clips, one part of which is cemented to the backs of the Vicracoustic panel, the other screwed to the wall.

The low frequency absorption of these panels is increased from 0.47 to 0.57 at 125 Hz if the Z-clips are mounted on 1 × 3 strips, but the advantage of doing so at other frequencies is almost nil. The treatment of Studios A, B, C and D is accomplished with carpet, low frequency Helmholtz resonators and Vicracoustic panels added to the built-in absorption of the drywall surfaces.

The placement of the Vicracoustic wall panels in Studio-A is shown in Fig. 14-10. Even though the east and south walls are splayed, an attempt is made to place panels on one wall to

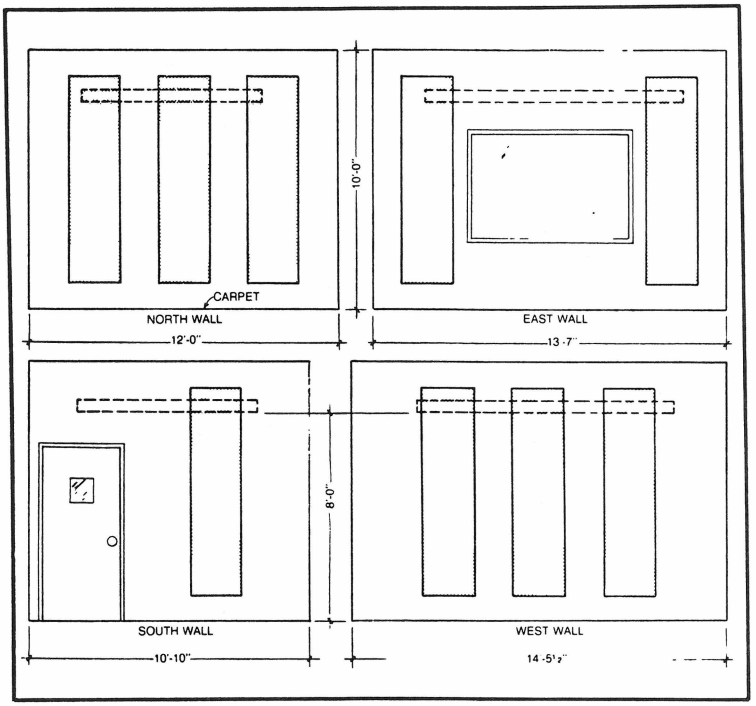


Fig. 14-10. Wall elevations of Studio A showing placement of Vicracoustic panels. The broken lines indicate relative position of the suspended frame holding low peak absorbing boxes.

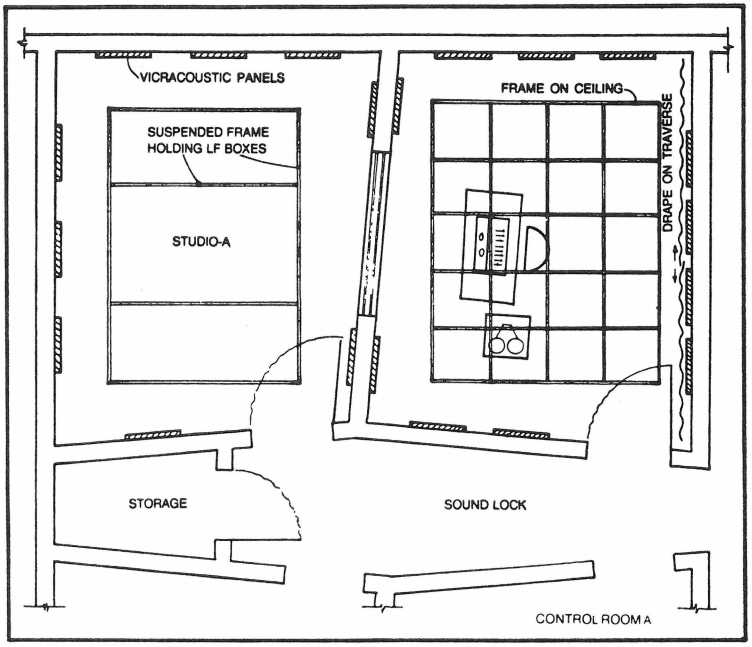


Fig. 14-11. Projected ceiling plan of Studio A and its control room showing position of the following acoustical elements: Vicracoustic wall panels, frame suspended from ceiling in Studio A, frame fastened to ceiling in Control Room A and drapery on traverse in Control Room A.

oppose bare wall (or window, or door) on the opposite wall. This can best be judged in the projected ceiling plan of Suite A in Fig. 14-11.

The constructional details of the low frequency absorbing boxes are given in Fig. 14-12. Similar to others considered in other chapters, the frame is of 1 × 8 lumber with a back of ½ inch plywood or particle board. The face of 3/16 inch masonite is filled with 3-16 inch holes drilled on 3 inch centers. This gives a perforation percentage of about 0.3 percent and a resonance peak in the vicinity of 100 Hz.

The 4 inches of 703 glass fiber broadens this peak. The boxes should be spray painted with flat black paint to reduce their visibility.

The 7 foot × 10 foot suspended frame is placed in Studio A approximately as indicated in the projected ceiling plan of Fig. 14-11. Figure 14-13 shows the relationship of the 1 × 6 frame and the plastic louver layer. The three fluorescent fixtures

assure that the plastic louver plane is the dominant visual feature of the room.

The 13 black low frequency boxes the frame contains will scarcely be visible. The placement of the low frequency boxes in the frame is important. Boxes 1, 2, 3 and 4 have their faces downward, resting on the open cells of the plastic louvers. Boxes 5 and 6 rest on their long edges and point north; 7 and 8 point south; 9 faces west; and 10 faces east. The three low frequency boxes 11, 12 and 13 resting on the fluorescent fixtures must, of course be directed upward.

It is well that these last three have some soft material between the boxes and the metal reflectors to avoid sympathetic rattles when the room is filled with sound. In fact, an awareness of the possibility of rattles in the entire assembly is advised.

REVERBERATION TIME OF STUDIO A

Table 14-1 lays out the details of calculating (estimating) the reverberation time of Studio A. A reverberation time of

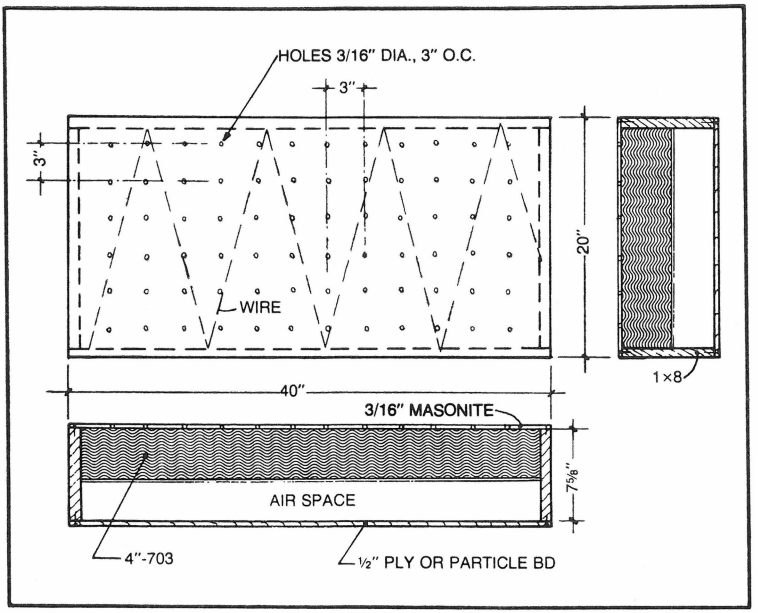


Fig. 14-12. Constructional details of Helmholtz type perforated face resonator which provides low frequency absorption to compensate for carpet deficiency in the studios.

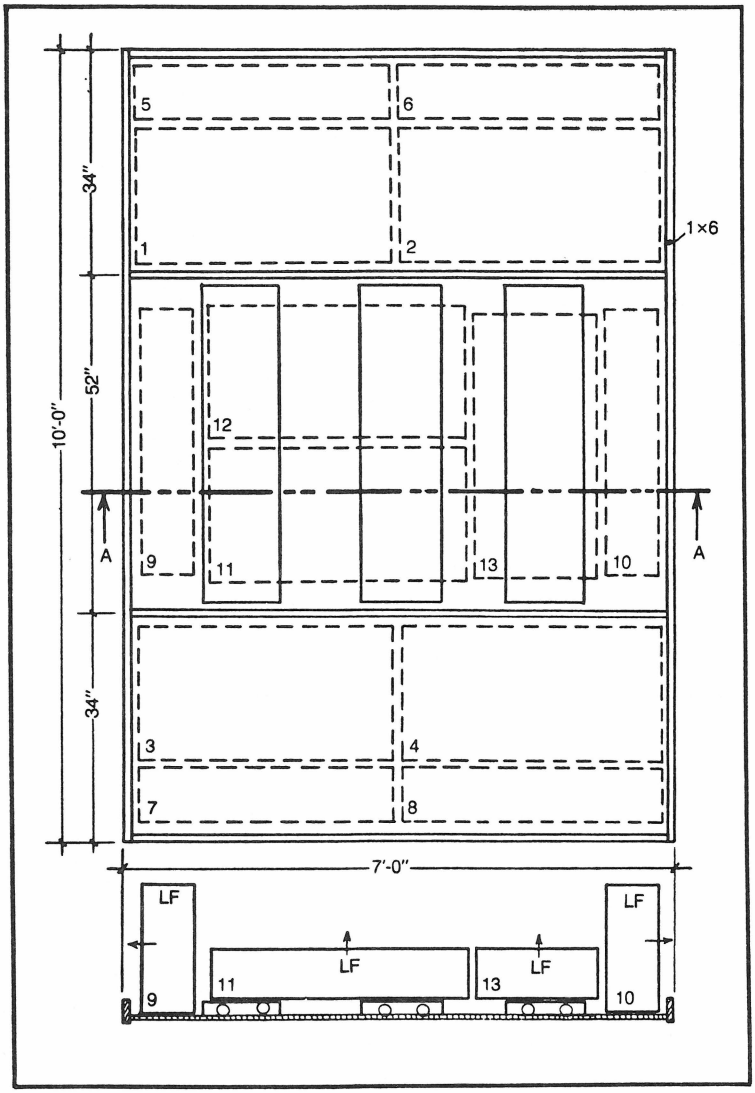


Fig. 14-13. Frame of 1 × 6 lumber suspended from the ceiling of Studio A which holds illumination fixtures and the 13 low frequency boxes required in the room. Some boxes face downward, some point upward and others point in the four horizontal directions.

0.3 second was the goal and the plotted graph for Studio A in Fig. 14-14 shows that this goal has been approximated. The exceptionally high absorption of the Vicracoustic panels at 250 Hz and 500 Hz generates the characteristic dip noticed in the

Table 14-1. Typical Speech Studio Calculations for Studio A

SIZE	Two walls splayed from basic rectangle 11'-5" × 13'-11", ceiling 10'
FLOOR	Carpet, heavy with pad, on floated floor
CEILING	Suspended frame holding 13 low frequency Helmholtz absorbers, 4 75 sq ft each
WALLS	Vicracoustic Type 80 panels (9) 2' × 8' × 2", perforated vinyl covering 2" glass fiber, furred out 1"
SURFACE AREA	828 sq ft
VOLUME	1,598 cu ft

MATERIAL	S Area Sq. Ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Carpet	160	0 05	8.0	0 15	24 0	0.30	48.0	0 40	64 0	0 50	80.0	0 60	96 0
Drywall	668	0.08	53 4	0 05	33.4	0 03	20.0	0 03	20.0	0.03	20.0	0.03	20.0
Low Frequency absorbers	62	1.0	62.0	0 68	42.2	0.39	24.2	0 17	10 5	0 13	8 1	0 10	6.2
Vicracoustic panels	144	0.57	82 1	0.98	141 1	0 92	132.5	0 76	109.4	0 71	102 2	0 78	112 3
Total sabins, Sa			205.5		240.7		224.7		203.9		210.3		234.5
Ave. Absorp. Coeff., a		0.248		0.291		0 271		0.246		0.254		0.283	
Reverberation Time, seconds		0.33		0.27		0.30		0.33		0.32		0.28	

control rooms and Studio C as well. An irregularity of this magnitude in the calculation stage has little significance unless confirmed by subsequent measurements. At that time, and not before, some trimming might be necessary and justified. The beauty of the modular acoustical treatment is that such trimming, if required, can be easily carried out.

ACOUSTICAL TREATMENT OF CONTROL ROOM A

The speech studios and control rooms are very similar in size and differ chiefly in the somewhat lower reverberation time goal of about 0.25 second for control rooms. Acoustically, a very major difference between the two types of rooms is that the floors of the control rooms are covered with vinyl tile instead of carpet. This factor means that the basic treatment will be accomplished primarily with wideband, or quasi-wideband, materials.

The grid of 1 × 6 lumber attached to control room ceilings makes 20 squares having inside dimensions of 24 inches × 24 inches which hold pads of 4 inches of 703 giving a total area of 80 square ft. The actual configuration is not too important, the effective area is.

Construction can follow similar frames described in earlier chapters with a fabric or screen facing. The air space between the 703 and the ceiling aids low frequency absorption of the material. The positioning of the ceiling frame is not critical, the position of Fig. 14-11 is suggested.

The placement of the Vicracoustic panels in typical Control Room A is shown in Fig. 14-15. The four panels on the east wall are normally hidden behind a drapery which is retractable. This drape is included to flatten the reverberation time at 1 kHz and above is very close to 0.25 second as shown in Table 14-2 and Fig. 14-14. If the drape is retracted the reverberation time in the same high frequency region is close to 0.3 second, making the 250 Hz dip stand out a bit more. This drape may be considered an approved variable acoustical element, if desired.

With the drapes extended over the east wall, conditions are proper for listening to sounds from the speech studio with its reverberation time of 0.3 second. With the drapes retracted, the control room becomes more adaptable acousti-

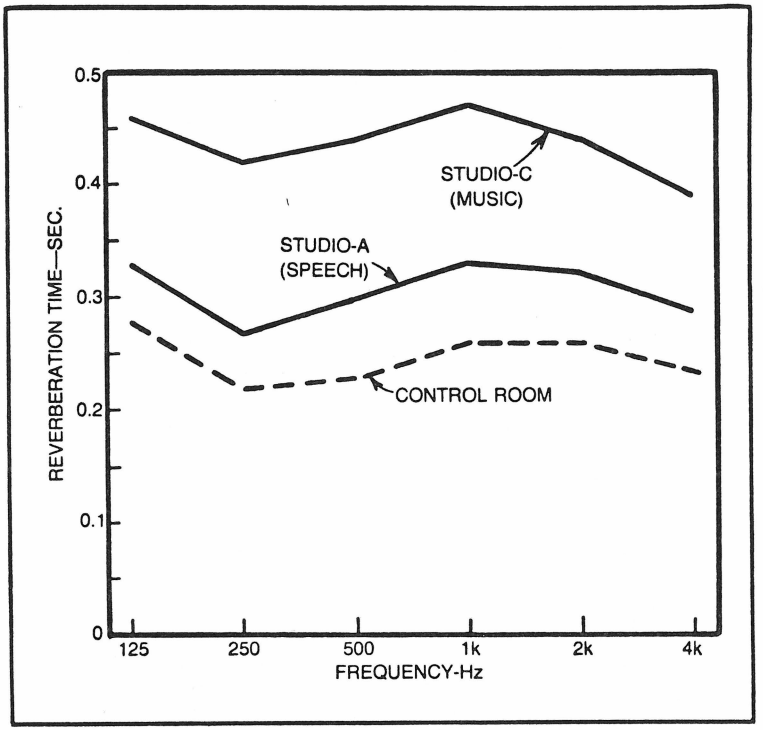


Fig. 14-14. Calculated reverberation time for Studio A as shown which compares to the goal of 0.3 second. The goal for Control room A is 0.25 second and for Studio C, 0.45 second. Measurements must verify such calculated estimates. The modular treatment plan allows trimming if required.

cally for recording an interview, for instance. The drapery material should not be too heavy (10 ounces per square yard material was used in the calculations).

Ordinary monks cloth, running about 8 ounces per square yard, is acceptable. It should be hung as close to the wall as possible and still clear the panels. Only enough material should be hung to result in the fold almost disappearing when the drapes are extended. Having deeply folded drapes would introduce too much absorption.

MUSIC STUDIO TREATMENT

Music Studio C should have a longer reverberation time than the speech studios for two reasons, its greater volume and the fact that the music is better served by a longer reverberation time than used for speech. A goal of about 0.45

EAST WALL
14'-5½"
10'-0"
VINYL TILE
NORTH WALL
10'-9"

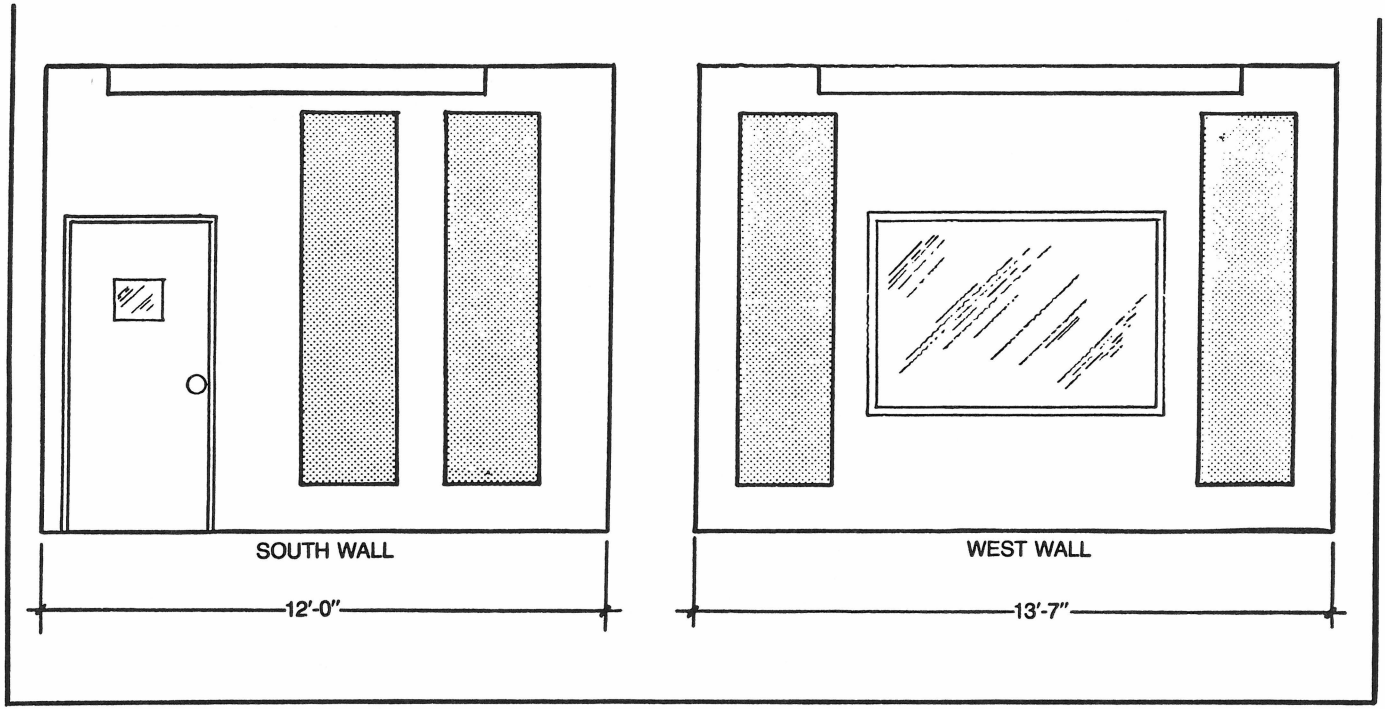


Fig. 14-15. Wall elevations of Control Room A showing placement of vicracoustic wall panels. The drape, normally covering the panels, is included to flatten the reverberation characteristic slightly. When retracted, the reverberation time in Control Room (A) is suitable for speech recording.

Table 14-2. Typical Control Room Calculations.

SIZE	Two walls splayed from basic rectangle of 11'-5" × 13'-11", ceiling 10'.
FLOOR	Vinyl tile over floated concrete
CEILING	Wood frame holding 80 sq ft of 4"-703
WALLS	Vicracoustic Type 80 panels (11), 2' × 8' × 2", perforated vinyl covering 2" glass fiber, furred out 1" Retractable drapery 9 × 14 10 oz sq yd, east wall
SURFACE AREA	828 sq ft.
VOLUME	1,598 cu ft.

MATERIAL	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Drywall	668	0.08	53.4	0.05	33.4	0.03	20.0	0 03	20 0	0 03	20 0	0 03	20 0
Wideband, ceiling	80	0.99	79.2	0.99	79.2	0 99	79 2	0 99	79 2	0 99	79 2	0 99	79 2
Vicracoustic panels	176	0.57	100.3	0.98	172.5	0 92	161 9	0 76	133 8	0 71	125 0	0 78	137 3
Drapery	126	0.03	3.8	0.04	5.0	0.11	13 9	0 17	21 4	0 24	30 2	0 35	44 1
Total sabins, Sa			236.7		290 1		275 0		254 4		254 4		280 6
Ave. Absorp. Coefficient, a		0.285		0.350		0 332		0.307		0 307		0 339	
Reverberation Time, seconds		0.28		0.22		0.23		0.26		0 26		0 23	

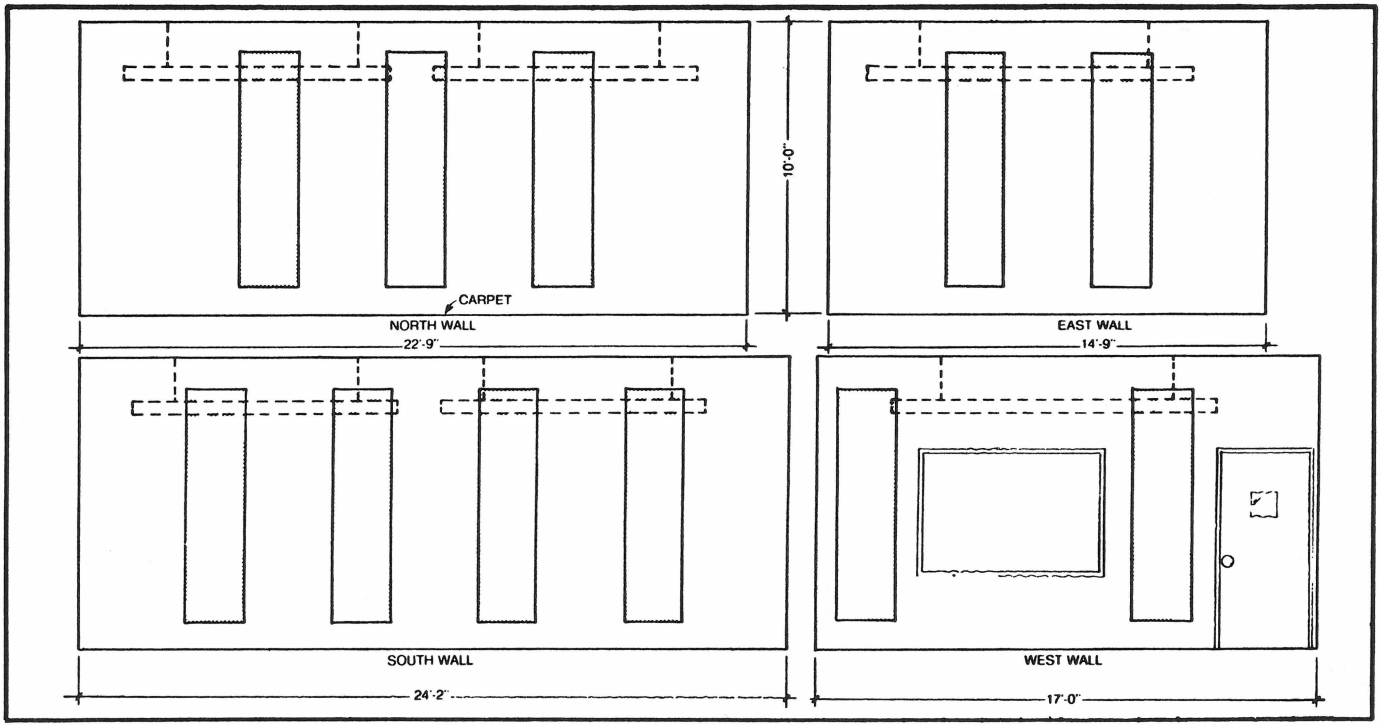


Fig. 14-16. Wall elevations of Studio C showing placement of vicracoustic panels in this music recording studio. Two suspended frames are required for illumination and to hold the low frequency boxes.

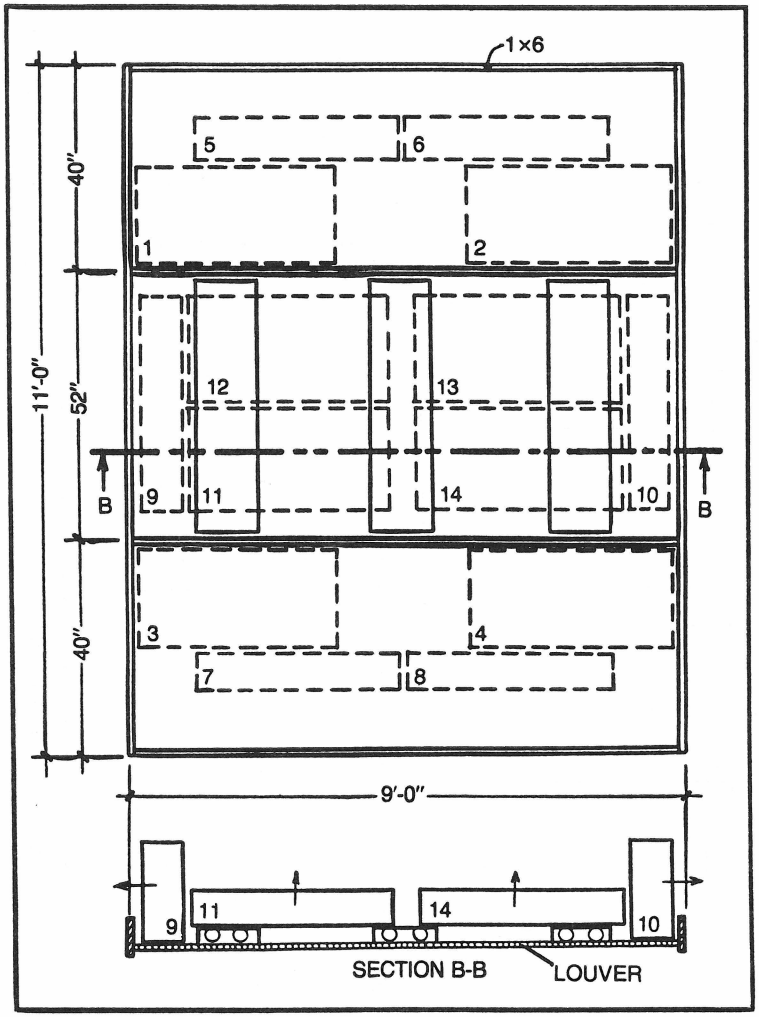


Fig. 14-17. Detail of one of the suspended frames in the music studio. The positions of the 14 low frequency boxes are indicated.

second was selected, compromising somewhat toward a speech requirement because the studio will be used for speech recording at times. In spite of its greater size, the music studio uses the same acoustical elements as the speech studios: carpet, Vicracoustic panels and peaked low frequency absorbers.

Figure 14-16 shows the placement of the Vicracoustic panels on the walls of Music Studio C. The suspended ceiling

Table 14-3. Calculations for Music Studio C

SIZE ..... Two walls splayed 5° from basic rectangle 16'-0" × 23-5", ceiling 10'.

FLOOR ..... Carpet, heavy with pad on floated concrete.

CEILING ..... Two suspended frames 9' × 11', each holding 14 low frequency Helmholtz absorbers, 4.75 sq ft each.

WALLS ..... Vicracoustic Type 80 panels (11), 2' × 8' × 2", perforated vinyl covering 2" glass fiber, furred out 1"

SURFACE AREA ..... 1,530 sq. ft.

VOLUME ..... 3,700 cu. ft.

MATERIAL	S Area sq. ft.	125 Hz		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz	
		a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Drywall	1,157	0.08	92.6	0.05	57.9	0.03	34.7	0.03	34 7	0.03	34.7	0.03	34 7
Carpet	370	0.05	18.5	0.15	55.5	0.30	111.0	0 40	148.0	0.50	185.0	0.60	222.0
Low Frequency absorbers	133	1.0	133.0	0.68	90.4	0.39	51.9	0.17	22.6	0 13	17 3	0 10	13.3
Vicracoustic panels	176	0.57	100.3	0.98	172.5	0.92	161.9	0 76	133.8	0.71	125.0	0.78	137 3
Total sabins, Sa			344.4		376.3		359.5		339.1		362.0		407.3
Ave. Absorp. Coeff., a		0.225		0.246		0.235		0.222		0.237		0.266	
Reverberation Time, seconds		0.46		0.42		0.44		0 47		0.44		0.38	

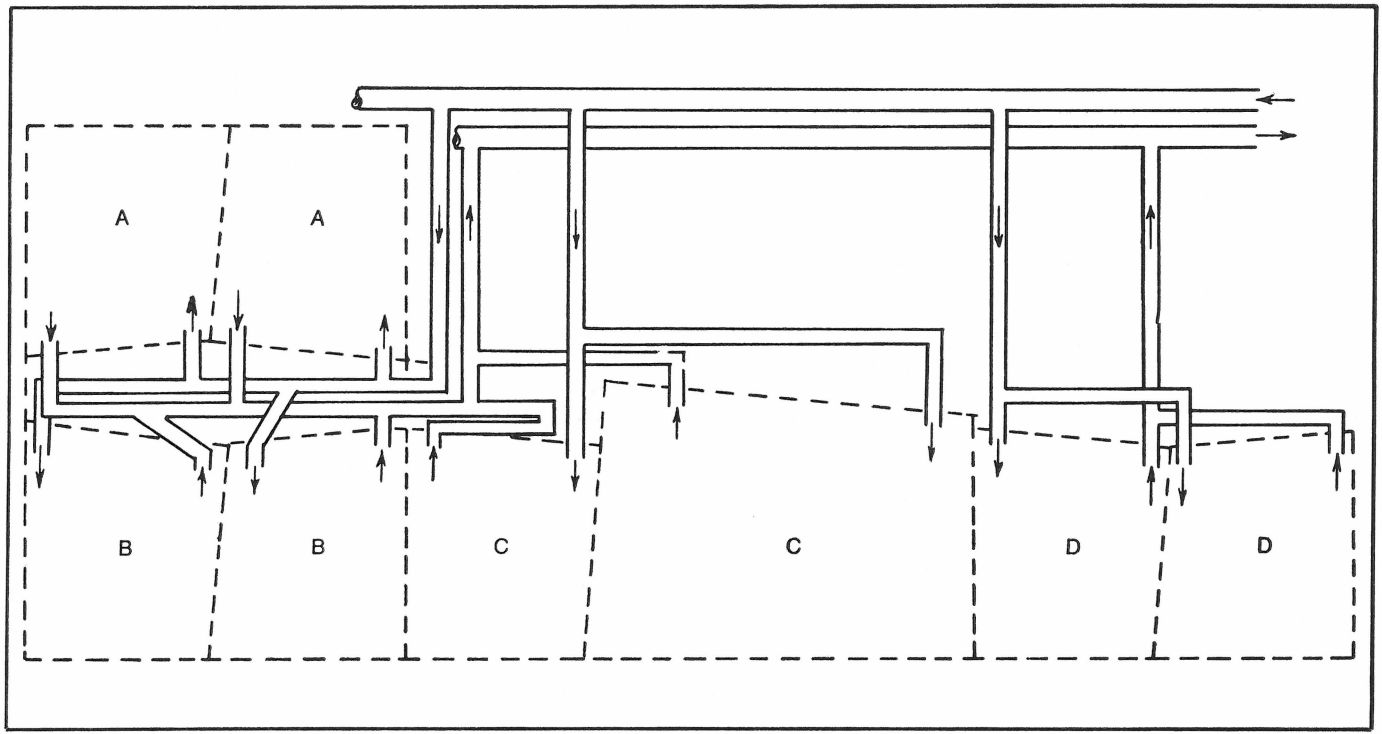


Fig. 14-18. Air handling ducting plan for the studio complex. This plan places a maximum length of ducting between grilles of adjacent rooms to prevent crosstalk from room to room via the duct. Lined ducts attenuate sound conducted along the ducts.

frames are shown with broken lines, the lower edge being about 8 feet above the floor. These frames each hold 14 of the same low frequency resonator boxes used in the speech studios and described in Fig. 14-12.

Figure 14-17 shows the configuration of the 14 low frequency boxes in one of the ceiling frames. In general, the plan is the same as for the speech studio frame: the perforated side of those standing on edge facing outward (5, 6, 7, 8, 9, 10): those resting on the fluorscent fixtures (11, 12, 13, 14) facing upward; and the rest (1, 2, 3, 4) facing downward.

Table 14-3 reveals the details of the calculation of reverberation time for the music studio. The calculated values of reverberation time are plotted in Fig. 14-14. The deviations from the goal of 0.45 second are not significant, but measurements should verify the actual shape which will then be the basis of any trimming adjustments considered necessary.

A/C DUCT ROUTING

In Chapter 2 the several basic principles concerning air conditioning ducts in studios were elucidated. Applying these principles to the present case of multiple studio suites, the plan of Fig. 14-18 resulted. Note that the maxium length of duct is placed between grilles of adjacent rooms or even rooms on the opposite side of the sound lock. Supply and return grilles in a given room should not be too close together to assure adequate circulation. In the Control Room C return duct, a U shaped section was inserted to avoid a short path to the adjoining room.

Chapter 15
Diffusion Confusion

All that is required of the acoustical consultant is that he design studios and other rooms that engineers, musicians and the general public consider "good." This is a difficult and subjective evaluation and the job definitely does not fall into the neat categories of definite black—white, go—no—go things of this world. If a room is too reverberant or too dead it is judged "bad" and adjusting reverberation within relatively close limits is probably the greatest single factor in elevating a poor room to a good or at least a better condition. However, reverberation time is not the only factor involved. Another factor is the diffusion of sound in the room. Often two studios very similar in size with the same reverberation time have a very different sound. This difference can quite probably be traced to diffusion of sound in the room.

The relationship of diffusion of sound in a studio to the general acoustical quality of that studio is something of a mystery that has baffled studio designers for the last half century. What is diffusion? The sound field in a studio is diffuse if at any given instant the intensity of sound is uniform everywhere in that room and at every point sound energy flows equally in all directions. It has to do with homogeneity of sound in a room. Such a diffuse condition is a basic assumption in the derivation of the reverberation time equations of

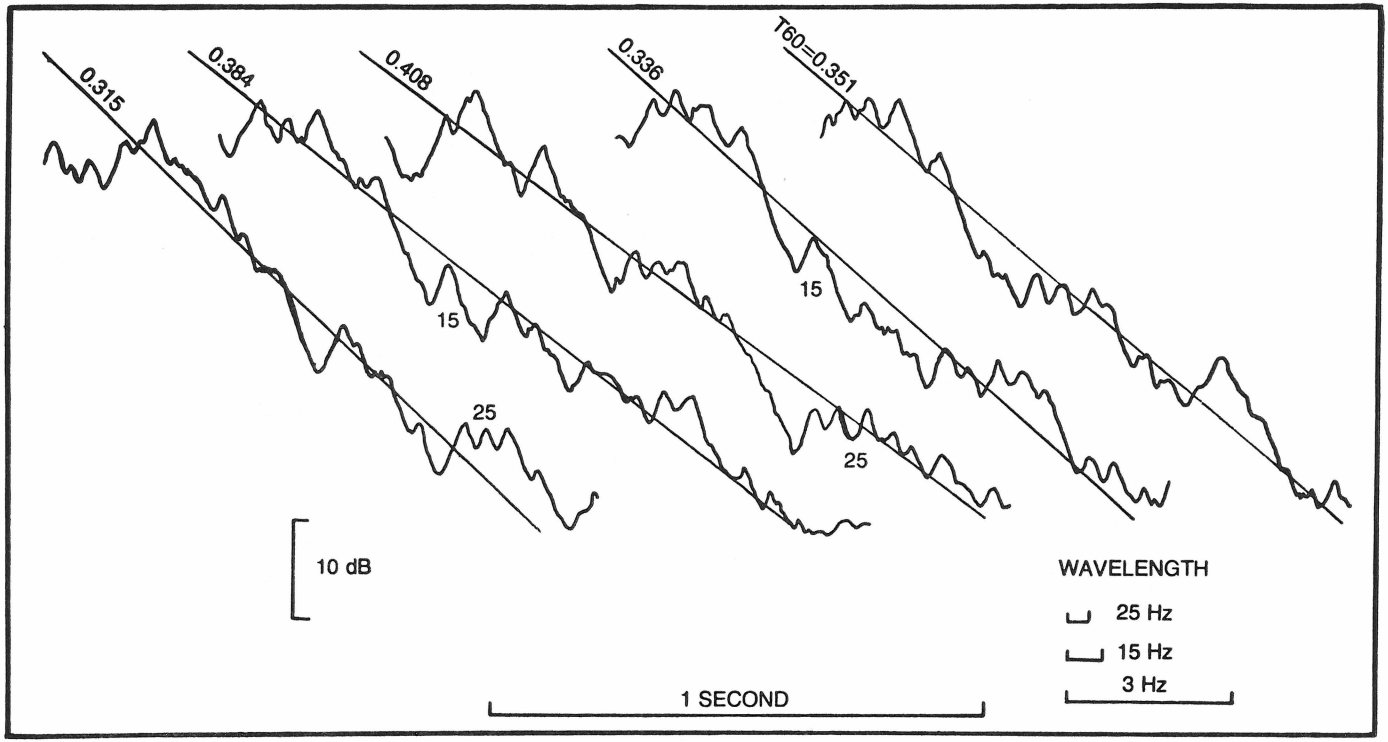


Fig. 15-1. Graphic level recorder tracings of successive reverberatory decays under identical conditions of an octave band of random noise centered on 125 Hz. Evidence of beats between axial mode resonances is apparent.

Sabine and Eyring. It is apparent that a dominant standing wave condition or knowledge that sound conditions vary throughout a studio means that a diffuse condition does not exist.

Diffusion is not the problem in large rooms such as auditoriums as it is in small rooms such as recording studios and listening rooms. The dimensions of the smaller rooms are comparable to the wavelength of sound to be recorded or reproduced in them.

In Chapter 1 the effect of room size was considered along with room proportions. It was noted that the more uniform the distribution of room resonance modes the better. This procedure contributes to the diffusion of sound in the room. Selecting a cubical space in which all axial modes pile up at certain frequencies with great empty spaces between these pile-up frequencies is a move away from reasonably diffuse conditions. It is impossible to attain truly diffuse sound conditions in a small space, but approaching it as closely as possible is a major goal in studio design.

SOUND DECAY IRREGULARITY

In the measurement of reverberation time the modes of the room are excited, say, with high intensity random noise from a loudspeaker. When the loudspeaker sound is suddenly terminated, these room modal frequencies die away, each at its own frequency and own rate.

Figure 15-1 shows tracings from graphic level recorder records of five successive decays of an octave band of random noise centered at 125 Hz. The loudspeaker and microphone positions remained fixed. Figure 15-2 shows similar five successive decays under identical conditions except it is for an octave band of random noise centered on 4 kHz. The contrast in smoothness of decay is striking, yet these are typical of small studio decays at these frequencies. It is instructive to dig into this a bit further.

The 125 Hz and 4 kHz decays of Fig. 15-1 and 15-2 were made in a small multitrack studio 13 feet–5 inches × 18 feet–5 inches with a ceiling height of 7 feet–6 inches, volume 1,853 cubic feet. The object of the measurement was basically the determination of the reverberation time of the studio.

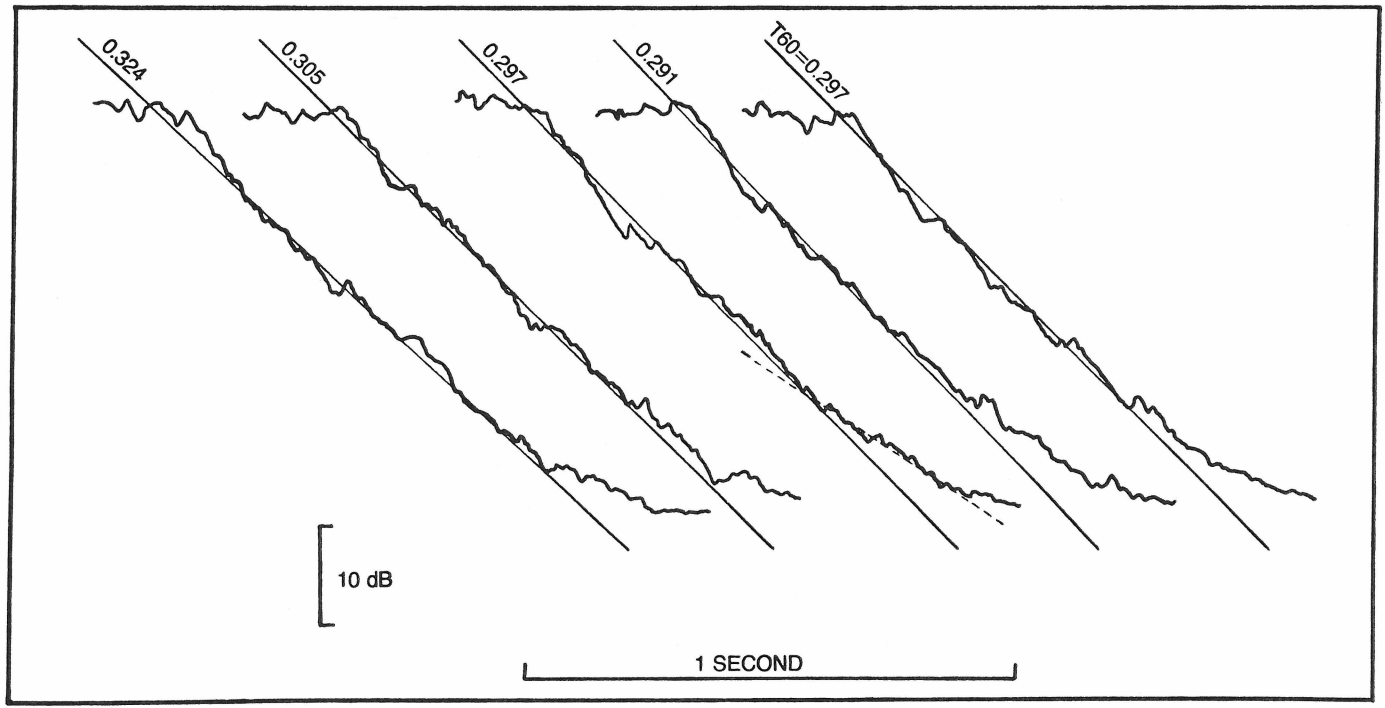


Fig. 15-2. Successive graphic level recorder tracings or decays under the same conditions as Fig. 15-1 except for an octave band centered on 4 kHz. An octave at this frequency contains so many modal frequencies that the decay is much smoother than an octave at 125 Hz. A second decay slope at low levels gives evidence of a slower rate of decay of certain room modes.

Establishing a best fit straight line average slope to the erratic decays at 125 Hz is far less precise than for the 4 kHz decays. To illustrate this, the *squint–eye slope* lines are included in Figs. 15-1 and 15-2 with the reverberation time (T_{60}) in seconds included at the top of each slope.

Of course, different observers would establish slightly different slope fits, but the averaging of five slopes for each frequency and each microphone position gives a statistically significant mean value.

The mean value for the five 125 Hz decays for each of three microphone positions in this studio is 0.291 second with a standard deviation of 0.025 second. The same for the 4 kHz octave is 0.311 second with a standard deviation of 0.013 second. The standard deviation (the plus and minus deviations from the mean value which includes 67 percent of the measurements) for 125 Hz is twice that for 4 kHz which reflects the greater fluctuations in the 125 Hz measurements.

Of special interest in this chapter, the reverberation decays of Figs. 15-1 and 15-2 also reveal something of the sound diffusion conditions in this studio. Octave bands of random noise were used in both the 125 Hz and 4 kHz cases. An octave band centered on 125 Hz is considered to include energy from 88 to 177 Hz, the half-power (3 dB down) points. The 4 kHz octave covers 2,828 to 5,656 Hz, the one spanning 89 Hz, the other 2,828 Hz. The 125 Hz octave band includes relatively few modal frequencies of the room, the octave at 4 kHz many.

The axial mode frequencies for this small multitrack studio below 350 Hz are shown graphically in Fig. 15-3. Although there are no pile-ups several pairs are very close together and wide gaps (compared to the approximately 5 Hz bandwidth of each mode) occur.

In Fig. 15-3 the span of the 125 Hz octave includes six modal frequencies. Each of these modes has its own decay rate determined by the absorption material in the room involved in that particular mode. A single mode, if excited and allowed to decay without influence of any other mode, would decay exponentially which gives a nice straight line decay on a dB scale as shown in Fig. 15-4A. Our octave containing the six

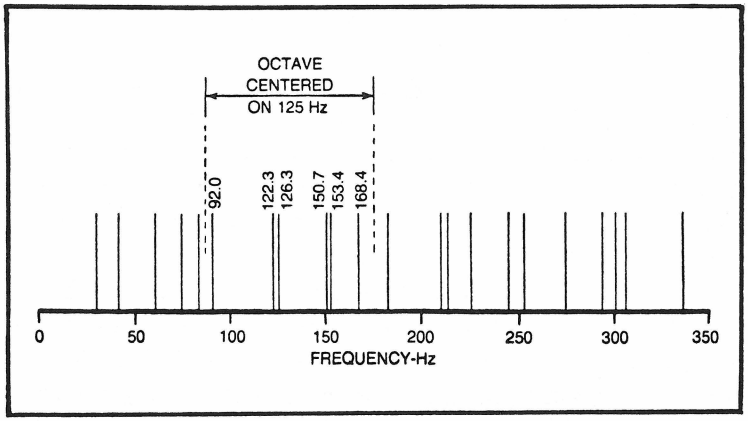


Fig. 15-3. The studio in which the decays of Figs. 15-1 and 15-2 were taken has axial modal frequencies as shown. The octave centered on 125 Hz passes only the six indicated. The close pairs within this octave tend to beat with each other causing fluctuations in the decay trace at the difference frequency.

axial modes of Fig. 15-3 might be considered a combination of B and C, as we have seen in Fig. 15-1.

Then how is the smoothness of the decay curves of the 4 kHz octave (Fig. 15-2) explained? We have seen that the 125 Hz octave is only 89 Hz wide while the octave centered on 4 kHz is 2,828 Hz wide. The greater smoothness is explained by the greater width and thus the greater number of modal frequencies included in the 4 kHz band. Only the axial modes are plotted in Fig. 15-3. It would be impossible to show graphically even the numerous axial modes within the 4 kHz octave, let alone the tangential and oblique modes. In fact, considering all three types of natural frequencies of this multi-track studio, something of the order of 800,000 modal frequencies exist in the 4 kHz octave band while only 328 exist in the 125 Hz octave band.

Of course, as pointed out in Chapter 1, the tangential and oblique modes have less influence than the axial, but they do have some effect and this effect would be in the direction of smoother decays and better diffusion.

The effect of *difference beat frequencies* between axial modes of Fig. 15-3 can be detected in the decays of Fig. 15-1. The graphic level recorder paper speed for both Figs. 15-1 and 2 was 100 mm per second and a one second scale is indicated on both of these figures. If the 153.4 Hz and the 168.4 Hz

modes beat together, a difference frequency of 15 Hz is produced.

One cycle of a 15 Hz signal is represented by the length of the line so indicated in the lower right hand corner of Fig. 15-1. In the second and fourth 125 Hz decays there are fluctuations closely matching this frequency. The 126.3 Hz and 150.7 Hz modes beating together would yield a difference beat frequency of 24.4 Hz.

There are fluctuations in decay one and three which are close to 25 Hz. The closely spaced modes near 125 Hz and 150 Hz (Fig. 15-3) would produce beats of 3.6 and 2.7 Hz. Variations corresponding to the more slowly varying beats near 3 Hz are more difficult to pinpoint, but there are even suggestions of these. In other words, the modal frequencies within the 125 Hz octave band account for the relatively great fluctuations of the 125 Hz decays.

The reason why the five decays are not identical or similar can be explained by the fact that the different modal frequencies were not all excited to the same level. The random noise signal constantly changes in amplitude and frequency (within the octave limits). It is entirely fortuitous as to what instantaneous amplitude and frequency were at the time the sound was interrupted to begin the decay. Warning is given that a very smooth low frequency decay could result from a dominant single mode, although with octave bands this is unlikely.

A very important indication of the diffusion of sound in this small multitrack studio is given in the low frequency reverberation decays such as in Fig. 15-1. If the fluctuations are very great, the diffusion is poor. The smoother the decays, the better the diffusion.

Quantitative evaluation of diffusion conditions are not yet available from such decays, but good qualitative comparisons are not only possible, but part of the arsenal of informed workers in studios.

Diffusion information may also be gleaned from decay curves at higher frequencies. In Fig. 15-2 the broken line indicates a fairly definite suggestion of a second slope. This is probably the result of certain modal frequencies having less contact with the absorbing material in the room (i.e., modes

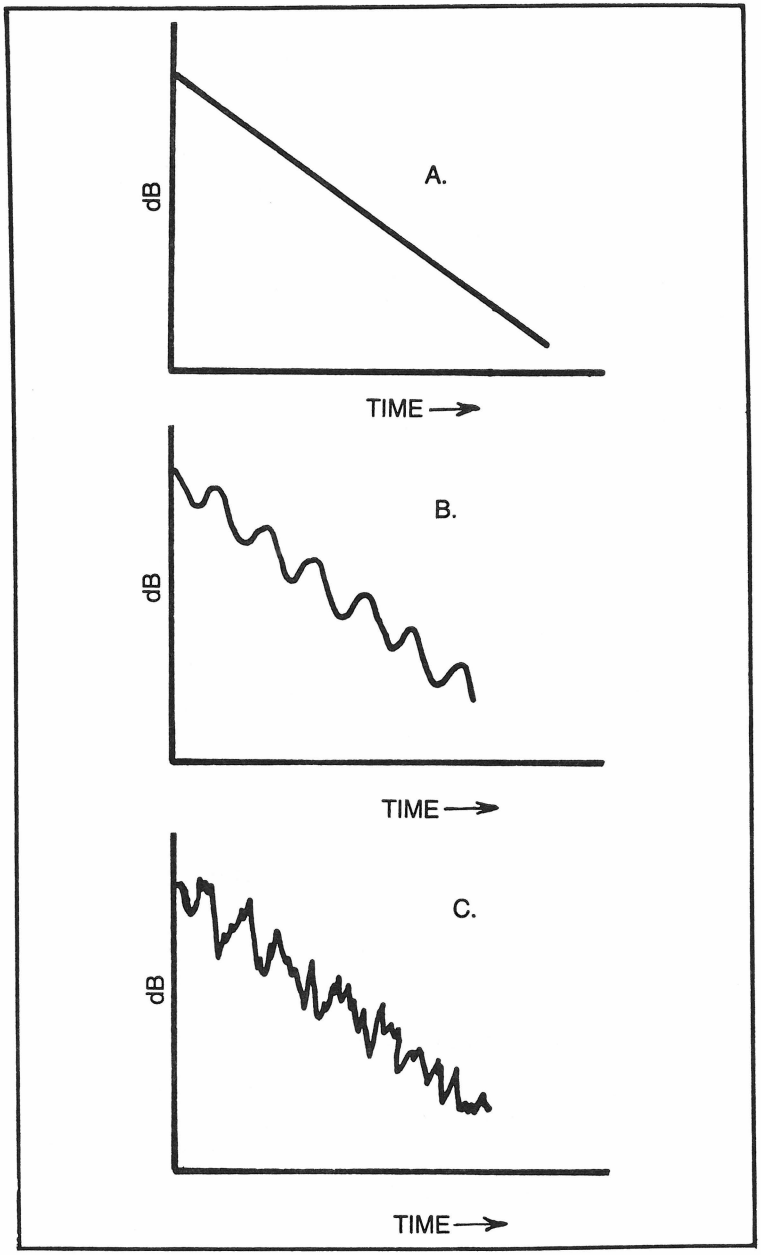


Fig. 15-4. (A) A single mode decays exponentially, giving a straight line decay on a logarithmic scale. (B) Two closely spaced modes, each having the same decay rate, beat with each other causing the decay to vary at the difference frequency. (C) Many closely spaced modes result in an erratic decay, the more modes the smoother the decay.

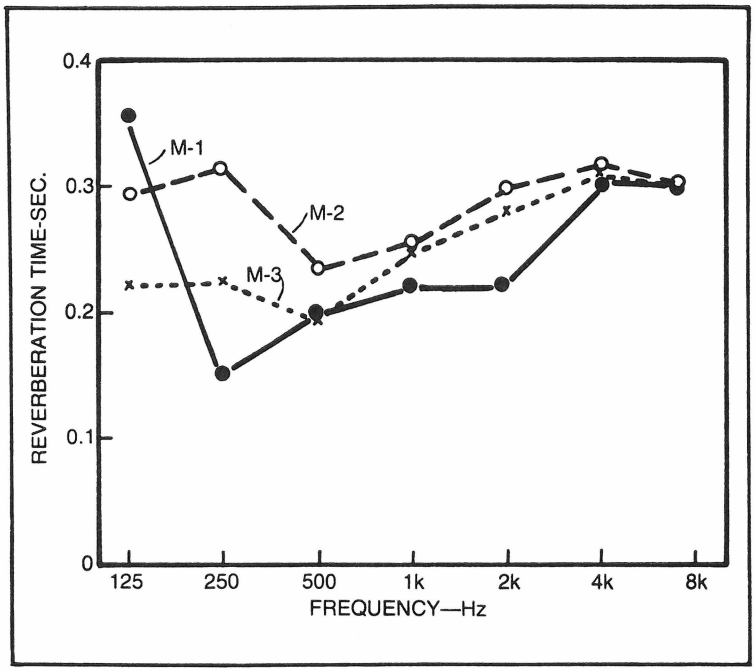


Fig. 15-5. Variation of reverberation time/frequency graphs with position in a small studio. The modal content of the octaves at different frequencies varies, and the decay rate of the different modes varies. To obtain a statistical picture of the sound field in the room, it is customary to average the measured reverberation times for each frequency at each position.

that are less damped) or modal frequencies not fully excited as the decay begins. In this particular case, these modes do not affect things until the sound has decayed 30 dB, hence their effect would probably not be detectable in normal program material.

VARIATION OF T_{60} WITH POSITION

Measuring reverberation time at different locations in a studio often reveals small but significant differences in reverberation time. These are usually averaged together for a better statistical description of conditions in the studio.

For example, Fig. 15-5 shows the reverberation time measured at three different microphone positions in the small multitrack studio mentioned in the previous section. It is noticed that the three graphs tend to draw together as frequency is increased. This suggests that such changes in re-

verberation time at different locations in the same studio are the result of a certain degree of non-diffuse conditions because we know that diffusion is better at high frequencies. Can this method then be used to evaluate the sound diffusion condition in a room?

The Engineering Research Department of the British Broadcasting Corporation asked the same question.[38] In their characteristically thorough way they measured reverberation time at 100 microphone positions in a 10 foot × 10 foot room. With no absorption material in the room (Fig. 15-6A), very diffuse conditions resulted in reverberation time long, but essentially constant throughout the room.

In Fig. 15-6B the reverberation time contours are shown when one wall was treated. The reverberation time is lower nearer the absorbing surface. They then demonstrated that geometrical diffusing elements on the untreated walls plus one absorbing wall resulted in quite complex contours. The laborious nature of this approach discourages further exploration of the method, although it shows some promise if special instrumentation were devised.

DIRECTIONAL MICROPHONE METHOD

The signal output of a highly directional microphone in a perfectly diffuse room should be the same no matter where it

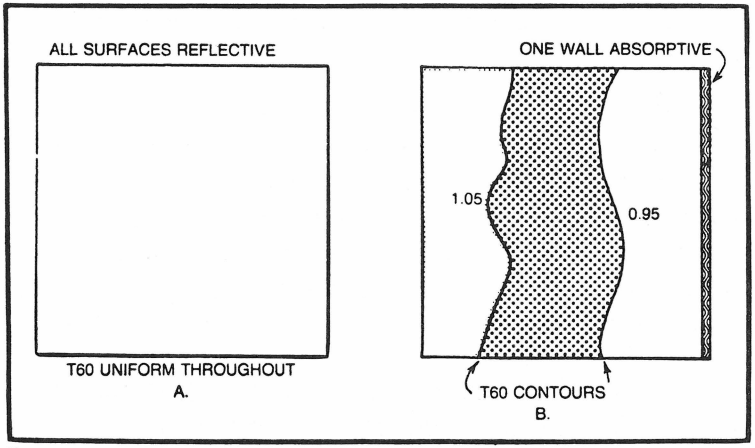


Fig. 15-6. (A) If all surfaces of a room are 100 percent reflective, the sound field is completely diffuse and the decay rate is the same at every point in the room.(B) If one wall is absorptive, the decay rate varies from point to point in the room. The contours of decay rate tend to be parallel to the treated wall.

is pointed, except when pointed at the source of sound. Ribbon microphones, with their figure-8 pattern have been tried. Parabolic reflectors with a microphone at the focal point have been tried as well as the line array type of directional microphone.

All of these methods have proved to be rather awkward to use and the results difficult to interpret. The greatest shortcoming of this method, from the point of view of small studios, is that sharp microphone directivity is hard to get at the low frequencies at which diffusion is the greatest problem. The prospect of this method of appraising diffusion in small studios is poor.

FREQUENCY IRREGULARITY

For the last 40 or 50 years there have been many serious efforts to evaluate diffusion in rooms by steady state transmission measurements.[39,40] Microphone and loudspeaker positions remain fixed. The constant amplitude swept sine wave signal radiated from the loudspeaker and picked up by the microphone has the room effect impressed upon it. This room influence should reveal something about the room.

Figure 15-7 shows typical frequency response records taken in a music studio of 16,000 cubic foot volume having a reverberation time of about 0.6 second at the 100-300 Hz frequency region under investigation. Two things are very striking:

- the magnitude of the variations
- the differences from position to position in the room

The amazing thing is that fluctuations in point to point response of such magnitude occur in studios having the best acoustical treatment and those considered excellent in subjective evaluations. The loudspeaker response in the 100-300 Hz region is included in these recordings, but it remains constant through all the tests.

If such wild fluctuations are to be of any help in evaluating studios, it is necessary to find some method of reducing them to numbers. Bolt has suggested the term *frequency irregularity factor* obtained by adding all the peak levels, subtracting the sum of all the corresponding dip levels and dividing the differ-

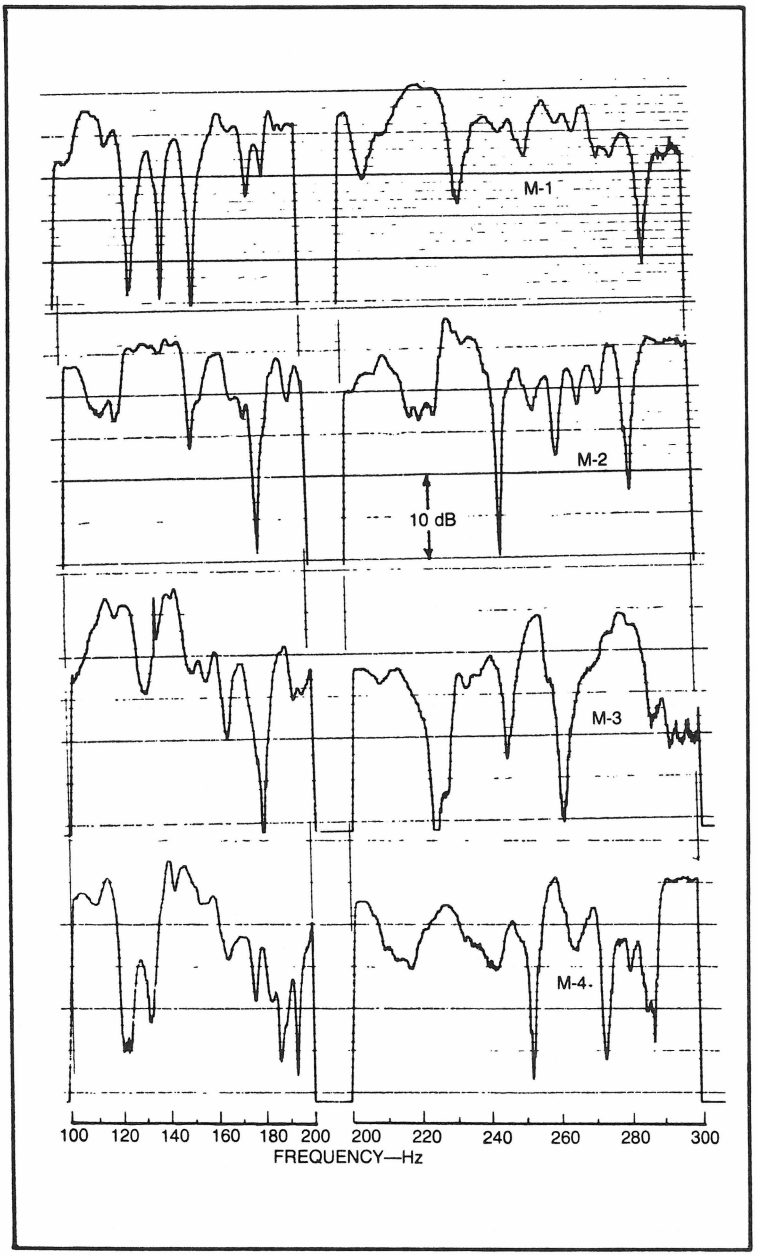


Fig. 15-7. Typical steady state swept sine frequency response records taken at different positions in a music recording studio having a volume of 16,000 cubic feet and a reverberation time of 0.6 second. The striking variations are an indication that even a well treated studio falls far short of truly diffuse conditions. At frequencies above 300 Hz, the curves become progressively smoother.

Table 15-1. Frequency Irregularity

Microphone Position	Frequency Irregularity Factor, dB/Hz		
	100-200 Hz	200-300 Hz	100-300 Hz
M-1	0.777	0.556	0.667
M-2	0.497	0.775	0.626
M-3	0.663	0.852	0.758
M-4	0.764	0.771	0.768
Mean	0.675	0.739	0.705
Standard Deviation	0.129	0.127	0.069

ence dB by the number of Hertz swept. This frequency irregularity factor, or simply *FI factor,* is in dB/Hz.

Applying this procedure to Fig. 15-7 yields the FI factors tabulated in Table 15-1. Comparison of FI factors for the different microphone positions would seem to tell us that conditions at M-2 are the best, considering the 100-300 Hz range, and that M-1 and M-2 are superior to M-3 and M-4.

Glancing back to Fig. 15-7 would seem to support this. What the FI factors of Table 15-1 tell us about sound diffusion in the room is not so clear. In measuring many studios it was noticed that larger FI factors were commonly associated with longer reverberation times. The 100-300 Hz FI factor for a dozen studios is plotted in Fig. 15-8 against their corresponding reverberation times. The broken line (not a least squares fit) would seem to indicate a definite relationship.

In fact, theoretical studies and experimental results have shown that at high frequencies *frequency irregularity* is related only to reverberation time and that it gives no additional information on diffusion of sound in the room. Whether or not this is true in the 100-300 Hz region remains to be seen.

One thing seems to be clear, if at a certain microphone position the swept frequency response is within, say, ± 5 dB, that would be a good spot for a narrator to sit.

A corollary to that observation is that it is possible to compare microphone positions by a swept frequency signal test. For such a test a good place for the loudspeaker would be in a corner of the room. If standing waves such as indicated by the runs of Fig. 15-7 exist in what are called well treated

studios, conditions may be less bad in some spots than in others. This is of operational value only if recording in a studio can be done with a single microphone in a fixed position.

SIZE AND PROPORTIONS OF ROOM

A minimum studio or control room volume of 1,500 cubic feet has been urged. This is step one toward better diffusion. Rooms smaller than this are often plagued with coloration problems, impossible or impractical to correct. Of course, rooms having substantially greater volumes but still in the general small room category have plenty of diffusion problems also, but the chances of achieving satisfactory conditions by the application of the methods to be described are better.

By making a room large in terms of the wavelength of the sound to be recorded in it means that the modal frequencies will be closer together which means improved diffusion. Most of the methods of diffusing sound in a room to be considered later are most effective at the higher audio frequencies. Optimizing the proportions of the room is one of the most effective ways to improve diffusion at the low end of the audible band. There are a number of steps in the acoustical treatment of a room which tend toward better diffusion of sound in the room, once the major basic matter of room size and proportions are set (review Chapter 1 in this regard).

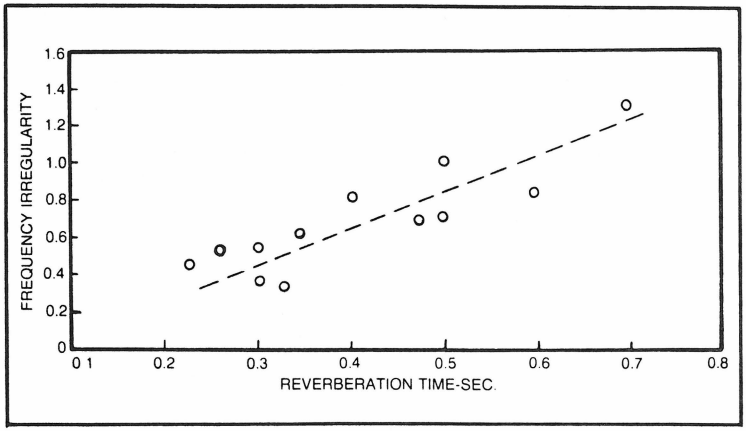


Fig. 15-8. The variation of measured frequency irregularity factor with studio reverberation time.

DISTRIBUTION OF ABSORBING MATERIALS

Numerous controlled experiments and practical experience have demonstrated that concentrating the required absorbing material on one or two surfaces of a room is an acoustical abomination. Common sense emphasizes that this procedure often leaves some opposing or parallel walls untreated, producing some axial resonances.

The application of absorbing material in patches has been established as far superior to application in fewer large areas. This accounts for the proliferation of wall modules and sectionalized ceilings in studio designs in this book. The patches of absorbing material may be distributed by determining the areas of the N-S, E-W and vertical pairs of surfaces and dividing the material between the three axial modes proportionally. At least, this is a respectable criterion to use as a rough guide, even though practical considerations of doors, observation windows, floor coverings, etc. demand compromise.

Another important contribution of patches of absorbing material is that diffraction of sound, especially at the higher frequencies, takes place at the edges of each patch. Such diffraction contributes helpfully to diffusion. Placing absorbent where it acts on every axial, tangential and oblique mode is too ambitious a goal, but remembering that all modes terminate in corners makes this an attractive location for absorbing material, but very limited areas are available near corners or edges of a room. Other factors, including appearance, often mitigate against this. Distributing absorbent in patches contributes to absorption efficiency as well as diffusion. Diffraction effects act as though the absorbent "sucks" sound energy from the surrounding reflective area which, in effect, increases its absorption coefficient.

SPLAYED WALLS

The conventional wisdom among studio people has long held that splayed walls aid in diffusion of sound. Splayed walls do have the ability to help in the control of flutter echoes between opposite reflective surfaces, but do they really contribute significantly to diffusion? Model experiments have

shown that the frequency irregularity factor is reduced with walls canted 5 percent but there is some question of this applying to practical studios with less smooth walls. The BBC made subjective tests in which experienced listeners listened with and without splayed walls with patches of absorbent on them and the results were inconclusive.

The rectangular and trapezoidal room shapes in Fig. 15-9 are called to the reader's attention. The broken lines repre sent the sound pressure modal contours for a simple mode for both shapes. The small arrows represent the directions of particle motion in the two cases. The trapezoidal room shape most certainly has contributed something to diffusion, but the magnitude of the contribution is small for walls splayed the usual one part in 5 or 10.

It appears that justification of splayed walls must come from reduction of flutter echoes rather than improvement of diffusion. As there are other ways to prevent flutter echoes (such as patches of absorbent) it would seem that tearing an existing building apart to cant walls might be ill advised. In new construction, however, inclining the walls might cost very little.

RESONATOR DIFFUSION

In low frequency resonators of the Helmholtz type, what happens to incident sound energy that is not absorbed by the system? It is scattered and scattering contributes to diffusion of sound energy in the room. This is not true of the porous type of absorbers in which energy not absorbed is reflected from the backing surface. It should be remembered, however, that high frequency energy not affected by a perforated or slat

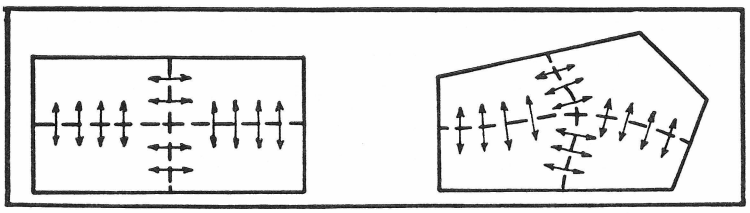


Fig. 15-9. The broken lines indicate the sound pressure modal contours for a simple mode in rectangular and trapezoidal rooms. The small arrows represent the direction of particle motion. It is obvious that the trapezoidal room shape contributes something to diffusion.

low frequency absorber can be reflected and contribute to a flutter echo problem. This would suggest facing such units with a high frequency absorber or inclining its surface.

GEOMETRICAL DIFFUSERS

There have been numerous, and presumably effective, geometrical protuberances employed in studios to diffuse sound. Common among these are semicylindrical (poly) diffusers[41] and diffusers of rectangular and triangular cross section. The polycylindrical surface has been widely applied in studios, not only for its low frequency absorption, but for its ability to take sound arriving from a given direction and reradiate it through an angle of 100 degrees to 120 degrees. This contributes positively to diffusion in the room.

In spite of the salutory effect of polycylindrical elements, both controlled experiments[42] and theoretical studies[43] have demonstrated the marked superiority of rectangular protrusions over both cylindrical and triangular. The rectangular protrusions produce some effect when their depth is as shallow as 1/7th of the wavelength. Thus a rectangular element 6 inches deep has some effect down to approximately 325 Hz. This effect works to change the normal modes of a smooth walled room. The cylindrical and triangular projections also do this, but to a lesser degree.

The acoustical distinguishing feature that sets the rectangular apart is the fact that it has finite portions perpendicular to the wall on which it is mounted. It has the ability of breaking up concentrations of modal frequencies better than cylindrical or triangular protrusions, of reducing the magnitude of dominant modes and lowering the frequency irregularity in swept sine transmission. This provides some support for the proliferation of the not-too-beautiful wall modules in studio designs already considered.

Other diffusing elements found in every studio, control room and listening room are people, tables, chairs, door and window frames and equipment of every sort.

GROOVED WALLS

In the future, one might look at a studio treatment and say, "Now that's really 'groovy'!" Another type of diffusing

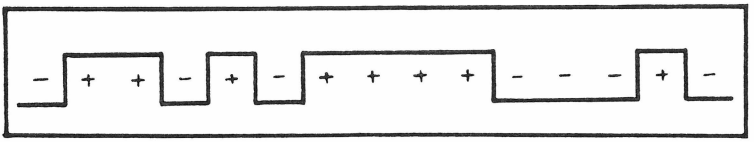


Fig. 15-10. Constructing walls having surfaces which alternate in a certain pattern between reflection coefficients of +1 and −1 (grooves a quarter wavelength deep) offer some future hope for diffusion of sound in a room. Good scattering is obtained ½ octave above and ½ octave below the groove frequency.

element which may find future acoustical application is that provided by *maximum length sequences* described by Schroeder.[44]

A wall having certain patterns of reflection coefficients alternating between +1 and −1 will scatter an incident plane wave evenly through a wide angle. This has been modelled with the more convenient microwaves with very good diffusing results.

The +1 and −1 reflection coefficients can be attained by construction of a wall with grooves a quarter wavelength deep giving the −1 coefficient. A typical maximum length sequence is shown in Fig. 15-10 which suggests a digital approach to studio acoustics. A sequence is calculated for a given frequency and it scatters well for ½ octave above and ½ octave below that frequency. Several octaves would be covered by making room surfaces in each of the three planes "groovy" for other design frequencies.

Chapter 16

Bits And Pieces Of Acoustical Lore

Features: Biscuit tin modules, nursery tray modules, tuning resonators, LF compensation under the carpet, the cheapest absorber.

Large absorbing modules of the wideband or low frequency peak type having appreciable air space behind a porous sheet are subject to a strange malady which degrades their absorption ability. There is the tendency for transverse modes of vibration being set up parallel to the face which decreases bass absorption. This can be prevented by breaking up the air space with dividers.

PARTITIONING OF AIR SPACE

The modules described in earlier chapters include dividers so that the maximum transverse dimension is generally around 2 ft. maximum. Partitioning an air space into an even greater number of small spaces can be quite expensive if lumber is used. Using lumber or metal sheets is not necessary because good performance can be obtained by breaking up the air space with corrugated cardboard dividers. Strips of corrugated board with width equal to the air space depth can be cut so that they fit together like egg crate dividers as shown in Fig. 16-1. Saw cuts with a buzz saw should make quite serviceable slots.

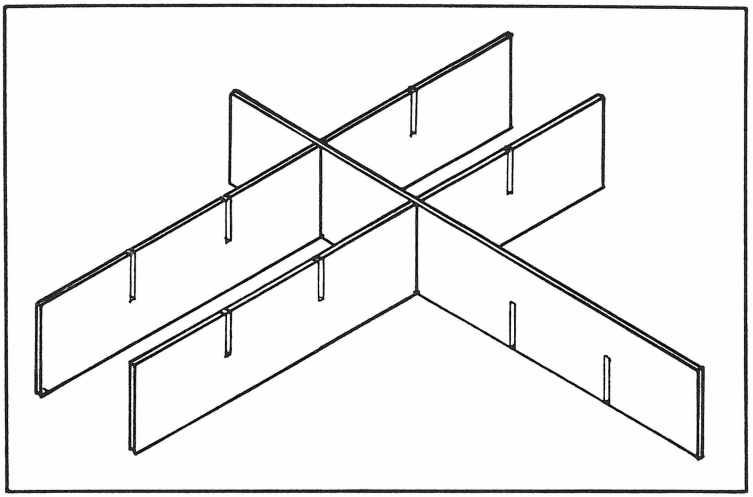


Fig. 16-1. Absorbing modules having subdivided air space within are more efficient than those having undivided air space. Corrugated paper dividers are effective in discouraging modes of vibration in the air space parallel to the face of the module.

BISCUIT TIN MODULES

Another way to partition the air space in absorbing modules is to make the modules the size of the partitioned space desired. Unit absorbers of modest size that can be readily arranged and attached to walls and ceilings also have many advantages in flexibility, sound diffusion and general absorption properties.

However, the availability of such in finished, manufactured form is almost vanishingly small. The late Sandy Brown, British musician-turned-acoustician, reported [29] a simple and cheap absorber built in a biscuit tin (cookie carton?).

Each tin box is about 8 inches × 8 inches × 5 inches deep with a lid having an opening almost as large as the box. A 1 inch thickness of rockwool with a wire screen cover is placed directly under the lid, leaving a 4 inch air space depth (Fig. 16-2).

This type of absorber was developed by the BBC and, apparently, was used for a time, but later abandoned because its low frequency absorption was too limited for the wideband absorber which it was supposed to be. This could be remedied only by thicker absorbent or deeper air space, both expensive,

and the whole idea of the biscuit tins in the first place was performance at minimum cost. However, the idea might just be useful to someone who has a studio treatment problem and, simultaneously, falls heir to a few hundred containers like biscuit tins.

NURSERY TRAY MODULES

After seeing and hearing of numerous horror stories concerning attempts to treat studios acoustically at minimum cost (egg cartons come to mind), the importance of truly budget absorbing modules is emphasized. Although all cases treated in this book are of the budget type, there is a spread even within that category.

Constructing wooden frames to hold glass fiber to walls and ceilings is expensive and very inconvenient. It is expensive in both materials and time. Further, the temptation is to make the wood modules larger than desirable to reduce the number to be made and hung. A small module which could be arranged in groups forming the equivalent of larger panels, or in various patterns and designs, would take advantage of the smaller size and exploit it to advantage.

The molded plastic trays nurseries use for small bedding plants offer some promise. Figure 16-3 shows two types of trays in common use. The tray of Fig. 16-3 (A) happens to be 15½ inches square by 1-⅝ inches deep. The large holes in the bottom give a perforation percentage of about 55 percent, that is, 55 percent of its bottom is in holes. These could be fitted with pads of glass fiber of 3 pounds per cubic foot density, 1½ inches thick and mounted to wall or ceiling surface with a few screws in the lip. The high perforation percentage means that this 1.7 square foot module would give the same absorption as 1½ inches of glass fiber without the plastic support. Any perforation percentage above about 15 percent or 20 percent would have essentially no acoustical effect. For much lower perforation percentages a Helmholtz resonator effect takes place. The 1½ inches of 3 pounds per cubic foot glass fiber would have very good absorption 1 kHz and above, and down to about 0.85 at 500 Hz, 0.4 at 250 Hz and 0.1 at 125 Hz. Therefore, it is obvious that low frequency peak absorbers

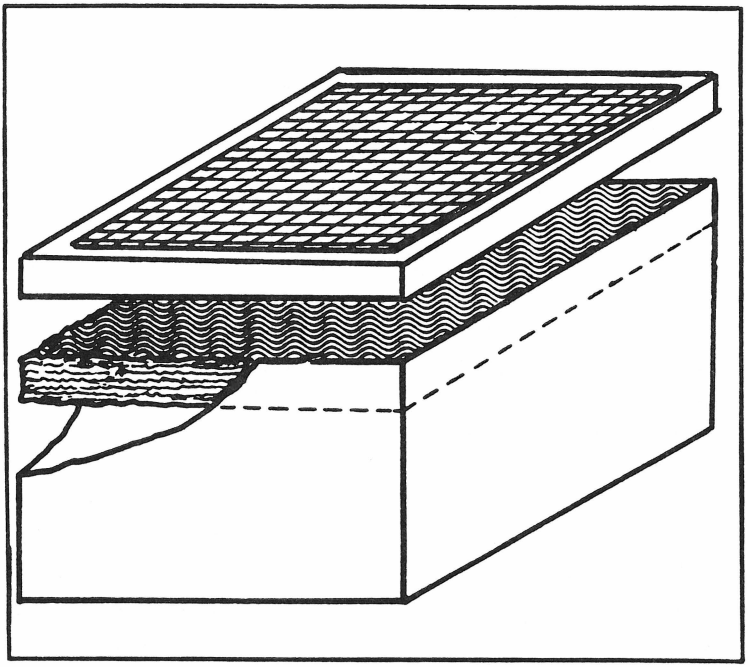


Fig. 16-2. The biscuit tin absorber is an efficient and inexpensive small module. Its use as a wideband absorber is limited because of its lack of low frequency absorption.

would be required to provide adequate compensation if any appreciable area of such modules were used.

Figure 16-3B is a nursery tray of somewhat different dimensions. It is 15½ inches × 16½ inches × 2½ inches deep and has a perforation percentage of slightly less than 10 per cent. There would seem to be two advantages of this tray over the (A) tray if a wideband absorber is desired. It will accommodate glass fiber of 2½ inch thickness, an inch thicker than (A), and the perforation percentage is down to where some Helmholtz effect would take place. Rough calculations indicate that it would resonate in the 350-400 Hz region which would tend to hold up absorption at the lower audio frequencies. Glass fiber of 3 pounds per cubic foot density of 2½ inch thickness would, without a cover or with a cover of high perforation percentage, be expected to yield excellent absorption down to 500 Hz, have an absorption coefficient of about 0.9 at 250 Hz and 0.4 at 125 Hz. It is anyone's guess what the

effect of the (B) cover would be, other than a general expectation of slower dropoff below 500 Hz.

The two trays considered require 3 pounds per cubic foot density glass fiber material of 1½ inch and 2½ inch thickness. The Owens-Corning Type 703 Fiberglas comes only in 1 inch and 2 inch thickness and splitting is not too convenient. The Johns-Manville Spinglass Series 1000 (3 pounds per cubic foot density) does come in 1 inch, 1½inch and 2½ inch thickness and would be equivalent in performance.

It is quite possible that nursery trays of many different sizes, depths and perforation percentages are available, or even that plastic containers of quite different type could be adapted to this absorption module service. Their adaptability to a given acoustical treatment job would require a bit of planning and application of the principles given here and elsewhere. Their appearance, with an artistic eye and a spray gun (before the cores are inserted, of course), could be novel and interesting. Their performance essentially could be what is expected of the glass fiber of the same size and distribution without the tray covers.

There is one effect here, however, which tends to give small patches a higher absorbing efficiency than larger patches of the same area. When absortion coefficients are measured in reverberation rooms, coefficients greater than unity are encountered at times. These measurements are made by determining the reverberation time and from that the number of sabins absorption added to the room by the sample of material being tested. The absorption coefficients are determined by dividing the number of sabins at each frequency by the area of the sample. When coefficients greater than unity result (i. e., absorption greater than 100 per cent) the advice is to consider it unity. The explanation usually given is that refraction effects at the edges of the sample under test make the sample appear larger, acoustically, than the physical size. By breaking the absorbent on a wall into small patches, refraction effects at the edges of all patches should give a greater absorption than calculated.

TUNING THE HELMHOLTZ RESONATORS

When a peak of sound absorption is needed at low audio frequencies to compensate for absorbers deficient at those

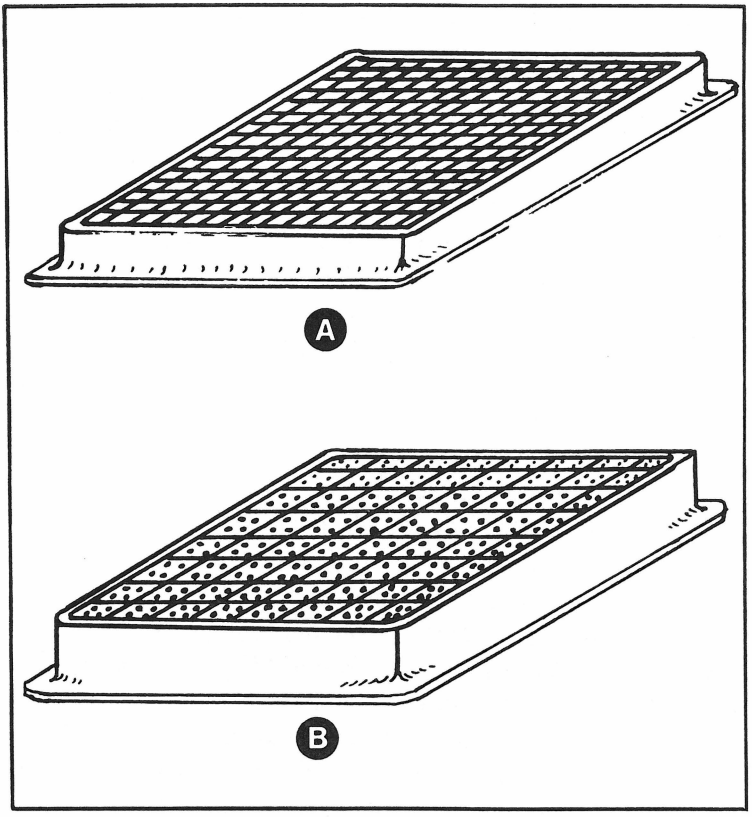


Fig. 16-3. Plastic nursery trays may be used as holders of dense glass fiber and used as absorbing modules which can be mounted in any desired pattern on walls. Tray A offers an area of about 1.7 square feet with a depth of 1⅝ inches, and a perforation percentage of 55 per cent. Tray B will accommodate glass fiber pads of 2½ inch thickness and has about the same area as (A) with a perforation percentage of only 10 per cent. These must be carefully selected to fit the job.

frequencies (carpet, drapes, acoustical tile, etc.), or a sharp peak is needed to tame a troublesome modal frequency, attention naturally turns to Herr Doktor Professor Helmholtz. Panel type absorbers generally peak in the lows, but the absorption coefficient rarely exceeds 0.3 at the peak while Helmholtz resonators commonly come close to perfect absorption (a = 1.0). There is really no theoretical difference between the slit type and the perforated type; consider a long slit nothing more than a row of holes. In the acoustical design of a room it is very helpful to know where the peak of absorption occurs. One way to estimate this is to calculate the

resonance frequency. Let us take the perforated resonator of Fig. 14-12 as an example:

Face panel .....3/16 inch masonite
Hole diameter .....3/16 inch
Hole spacing .....3 inches on centers
Depth of airspace.....7-⅝ inches

The frequency of resonance of a perforated panel absorber backed by a subdivided air space is given approximately by [5]

$$f_o = 200 \sqrt{\frac{p}{(d)\ (t)}}$$

where,

f_o = frequency of resonance, Hz
p = perforation percentage
t = effective hole length, inches
= (panel thickness) + (0.8) (hole diameter)
d = air space depth, inches

The figuring of perforation percentage is easily accomplished by reference to the sketch of Fig. 16-4 and is found to be about 0.31 per cent. The effective hole length is t=3/16 + (0.8) (3/16) = 0.34 inches, approximately. With these numbers and the air space depth of d = 7.6 inches we can estimate the resonance frequency as follows:

$$f_o = 200 \sqrt{\frac{0.31}{(7.6)\ (0.34)}} = 69 \text{ Hz}$$

The effective hole length is quite uncertain, being dependent upon the geometry, and the (0.8) (hole diameter) correction is only an approximation.

The indication of a frequency of resonance near 70 Hz is where the peak of absorption is expected to appear and the magnitude of that peak is close to a = 1.0.

Now, what is the shape of the absorption curve so that absorption calculations can be made at other frequencies? This information is best obtained from actual measurements on perforated absorbers, but few such measurements have been reported in this country. Some of the most complete measurements of this type have been reported by the Russian, V. S. Mankovsky. [45] From his excellent book are selected three Helmholtz type resonators with perforated faces. The physi-

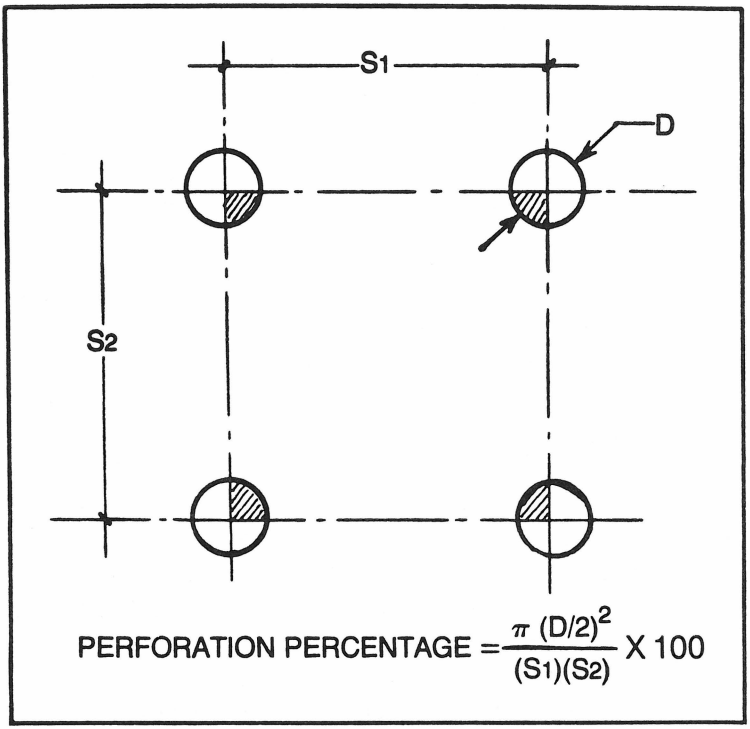


Fig. 16-4. The perforation percentage of an extended area is easily calculated from its smallest repeat pattern.

cal dimensions (translated from metric to closest English equivalent) and other pertinent data are given in Table 16-1.

The measured absorption coefficients are plotted in Fig. 16-5 and it is tacitly assumed that Russian measurement techniques are at least roughly equivalent to those in other parts of the world.

A comparison of graphs A and B dramatically show the effect of absorbent in the air cavity. The peak of graph B is so sharp it fell in the cracks between the 250 and 500 Hz measurement points but the broken line indicates a reasonable guess as to its shape. Without absorbent, this type of resonator has a tendency to "ring," i.e., to die away slowly when exciting sound ceases.

A great widening of the absorption peak and slight shift in resonance frequency results from the use of absorbent in the air space. Although the absorbent used (called PP-80) has not

Table 16-1. Data on Graphs of Fig. 16-5

Graph	Depth of Air Space	Thickness of perforated plywood	Hole Diameter	Hole Spacing	Perforation Percentage	Filled with Rockwool ?
A	2"	5/32"	5/32"	1-9/16"	0.785%	Yes
B	2"	5/32"	5/32"	1-9/16"	0.785%	No
C	2"	5/32"	25/32"	2-⅜"	8.5%	Yes

been identified by translator or editor, it is reasonably sure that it is common rockwool or glass fiber. The calculated resonance frequency applicable to the A and B graphs is about 467 Hz, which is not very close to the peaks determined experimentally.

Graph C is included to show the effect of a high perforation percentage, 8.5 per cent. The depth is the same as A and B, panel thickness is the same, but hole diameter and spacing are different. The graph C in Fig. 16-5 is very broad. The calculated frequency of resonance in this case is 466 Hz which is in good agreement with the measured values of graph C. At such high perforation percentages the point is approached at which the cover has no Helmholtz effect. For example, 15 per cent perforation percentage (or open space) is used for covers for wideband absorbers.

To apply data such as shown in Fig. 16-5 to any problem at hand is quite difficult in this form. Shapes vary as well as location of resonance peaks. These perforation percentages could well apply to absorbers tuned to other frequencies by using different air space depths. For example, the perforation percentage of 0.785 per cent applied to a box made of 1 × 8s (7-⅝ inch depth) would resonate in the vicinity of 120 Hz.

If this is where a peak is desired, how can graph A data be shifted down to this resonance frequency to give an estimate of coefficients to use based on the measured A values? In Fig. 16-6 the measured curves of Fig. 16-5 are brought together in what is called *normalized form*. These, in turn, can be applied to systems of other resonance frequencies. For example, graph A actually peaks at 270 Hz. At $2f_o = (2)\ (270) = 540$ Hz the absorption coefficient is read from graph A, Fig. 16-5, and found to be 0.42. This is plotted in Fig. 16-6 at $2f_o$ as part of the normalized representation of graph A. The same is done to

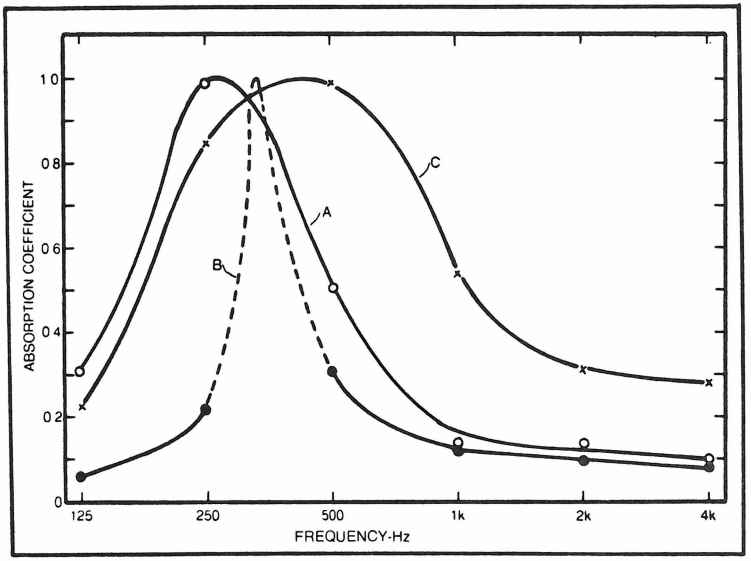


Fig. 16-5. The absorption characteristics as measured by Mankovsky of three Helmholtz perforated face absorbers as specified in Table 16-1. Curve B is for a unit with no absorbent in the cavity. Curve A is for the identical unit with absorbent. Note the shift in resonance frequency and broadening of the peak resulting from introduction of the absorbent. Curve C is for a similar unit with much greater perforation percentage.

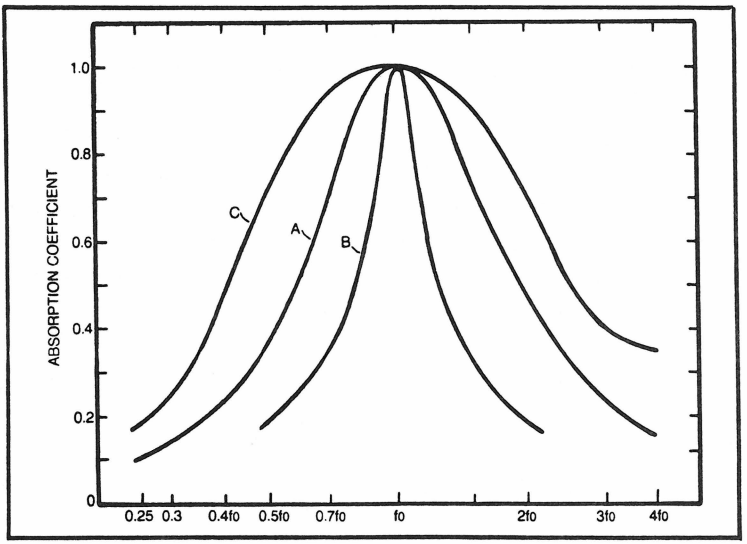


Fig. 16-6. The three curves of Fig. 16-5 are repeated here in normalized form to assist in applying the curve shapes to other design tasks to estimate absorption coefficients to meet specific needs.

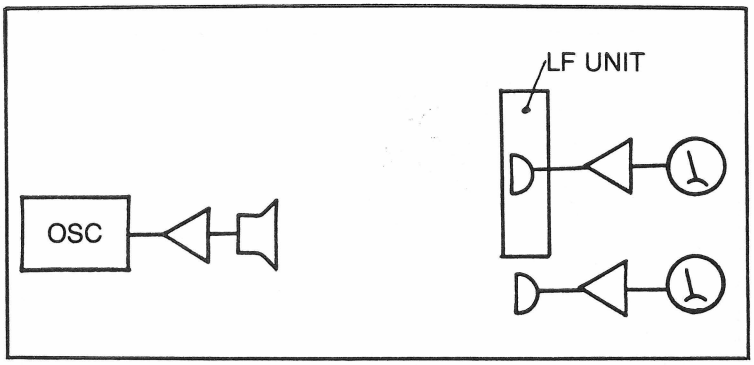


Fig. 16-7. The resonance frequency of a Helmholtz type absorber may be obtained experimentally outdoors as shown. The rise of pressure inside the box is detected by a microphone placed in the box as the frequency of the sound from the loudspeaker is swept through the range of interest. A second system measuring the sound pressure outside the box is a possible refinement to separate out instrumental variations in sound pressure.

complete all three graphs in Fig. 16-6. An example of the use of the normalized graph A would be to build up an absorption graph using, for example, the f_o = 120 Hz obtained for the boxes 8 inches deep and perforation percentage of 0.785 per cent. At 120 Hz a = 1.0. At $2f_o$, = 240 Hz a = 0.42, at $4f_o$ = 480 Hz a = 0.15.

The same can be done for $1.5f_o$, $2.8f_o$ and other points in between, as well as for frequencies below the resonance peak. Another approach would be to trace graph A of Fig. 16-5 on a sheet of tracing paper and then slide the paper to the left until the peak coincides with 120 Hz. The absorption coefficients with the new tuning can then be read off on the assumption that the shape of the curve would not change for such a modest shift in frequency. These two approaches give, at least, something to use, even though the accuracy leaves something to be desired.

Some cases have been noted in which the calculated frequency of resonance does not agree very well with measured peaks of absorption. A relatively simple method of measuring the frequency of the absorption peak of a Helmholtz resonator is diagrammed in Fig. 16-7. A loudspeaker is driven by a sine wave oscillator. The resonator under test is placed 6 to 10 feet from the loudspeaker with the perforated face toward the loudspeaker. A microphone, placed inside the box,

drives an indicator calibrated in decibels, preferably a sound level meter.

As the frequency of the oscillator is swept past the resonance point, a significant increase in reading will correspond to the great increase in sound pressure in the box at resonance.

If the oscillator output, the amplifier response and the loudspeaker response are all constant with frequency, the box pressure indications are accurate. A second sound pressure measuring system with its microphone the same distance from the loudspeaker as the one inside the box could be used to measure the pressure outside the box and yield corrections for the other. However, if only the frequency of the peak is desired, just note the frequency at which the microphone in the box indicates the peak.

Such a test, made on the Helmholtz resonator of Fig. 14-12 with a graphic level recorder making a hard copy of the

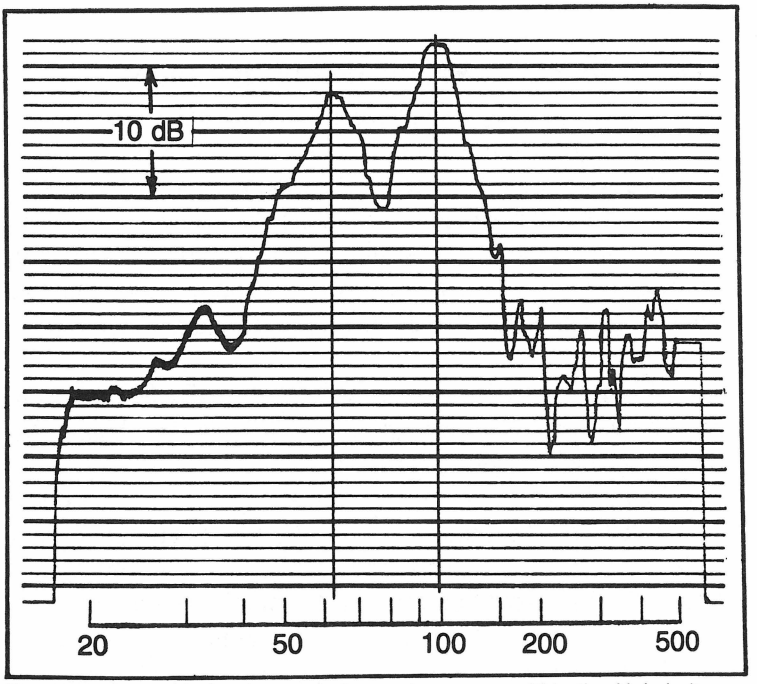


Fig. 16-8. A graphic level record of sound pressure within the Helmholtz resonator of Fig. 14-12 as the frequency is varied. The peak at 100 Hz is probably the Helmholtz peak and the one at 63 Hz a resonance of the back or face panel.

peak, is shown in Fig. 16-8. Surprisingly, a double peak was found. At first, transverse modes in the air space of the box were suspected, but this theory was rejected when the use of corrugated cardboard dividers in the air space had no effect on the double peaks. Panel resonance of the face and back of the box were then studied. The 3/16 inch masonite cover resonates at a calculated frequency of about 69 Hz and the ½ inch plywood back at about 51 Hz. The calculated resonance peak of the resonator action is 69 Hz. Checking the accuracy of such calculated resonance points is what this section is all about, but pinpointing just what causes which peaks in Fig. 16-8 is somewhat doubtful, although the higher peak at 100 Hz is probably the Helmholtz action and the peak at about 63 Hz is due to panel action, possibly of both front and back acting together.

The sound pressure within the resonator box is increased about 22 dB at resonance. This corresponds to a 13-fold increase in pressure. The double peak characteristic may actually be an advantage in that high absorption prevails over close to an octave.

LOW FREQUENCY COMPENSATION IN THE FLOOR

This is an idea whose time may not yet have come, at least for general application. However, it seems good enough to consider here as it stretches the imagination and points to a possible wider use in the future. There is no denying that it is nice to have carpets in studios, control rooms and other listening rooms. Nor is there any way to deny their acoustical effect: high absorption in the highs, low absorption in the low frequencies.

If only a special carpet pad were available that would absorb well in the lows and very little in the highs. Just compensating for the carpet, the problem would be solved. The Japan Victor Company expended great effort in one of their small Tokyo studios to sweep the solution to the problem under the carpet, so to speak.[46] The novel way they did this was to lay the carpet on top of a Helmholtz resonator array. Under the carpet and pad of 1.6 inch thickness is a perforated board and cemented excelsior board of 3.5 inch thickness. Under that is 5.5 inches of air space. A neat solution, to say the least. This eliminated unsightly boxes, or other special ceiling

or wall treatment to gain the required low frequency absorption.

The JVC solution is effective, although rather costly for general use. Is there a less expensive way of placing low frequency absorption under the carpet? Recent improvements in the Proudfoot Soundblox (The Proudfoot Company, Inc. P. O. Box 9, Greenwich, Connecticut 06830) suggest a possible solution. Soundblox are proprietary concrete blocks utilizing the cavity inside plus carefully designed slots, metal septa and fibrous filler as Helmholtz resonators. Figure 16-9 shows the appearance and cross section of one of the many types available, the 8 inch Type R block.

All the elements of a Helmholtz resonator are there along with the compartmentation effect of the metal septum and the fibrous filler to improve and widen the absorption effect. In

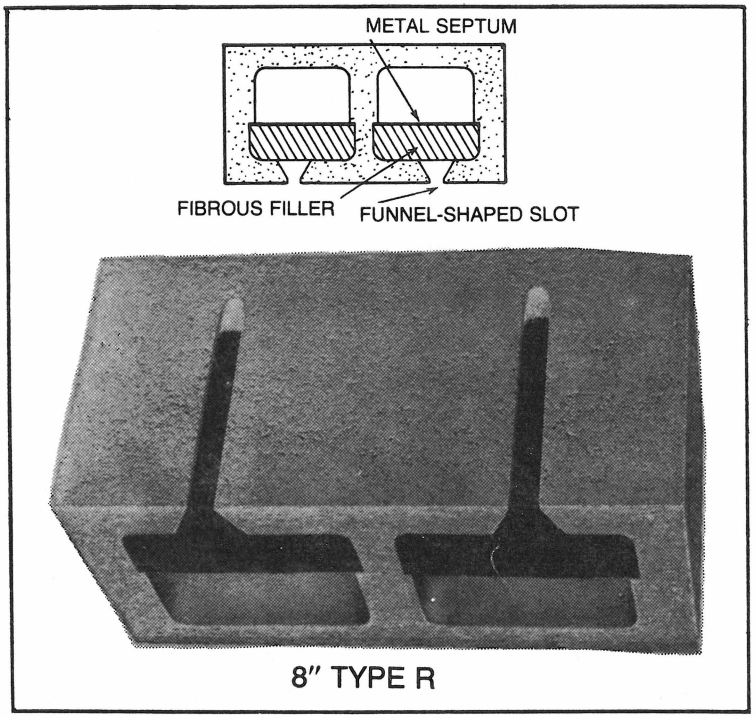


Fig. 16-9. The proprietary 8 inch Type R Soundblox concrete block which is a Helmholtz type sound absorber having the absorption characteristics shown in Fig. 16-10. The sound absorption is increased by dividing the cavity with a metal septum and the use of funnel-shaped slots.

Fig. 16 -10 is a plot of the measured absorption coefficients of the 8 inch Type R Soundblox. The broken line graph shows the absorption coefficients of a typical heavy carpet taken from the book [35] to show that the carpet absorbs well where the Soundblox is diefficient, and vice versa.

If 100 square feet of carpet and 100 square feet of Soundblox were placed in separate locations in a room, the coefficients would be proportional to the sabins absorption of each patch and the problem would be one of simple addition to get their combined effect. If carpet is used over the Soundblox only the sound not absorbed by the carpet reaches the Soundblox. The Soundblox can act only on the sound energy reaching it, which is less than that falling on the carpet by the amount the carpet absorbs.

However, at the low frequencies carpet is almost transparent to sound where the Soundblox have their peak of absorption. In this case, the blocks absorb what the carpet does not. At 4 kHz the reverse tends to be true and in less definite form. The carpet allows 40 per cent of the energy to pass through it and the Soundblox absorb only 40 per cent of this. Thus the combined effect is a bit complicated: certainly adding coefficients to obtain the combined effect is not legal.

Placing a layer of Soundblox, slots up, on the studio floor under a carpet is then, a possibility to compensate for the acoustical effect of the carpet. There is the problem of mechanical strength of the Soundblox to withstand a concentrated load such as a grand piano leg. Certainly some load distributing layer is necessary between the carpet and the Soundblox. The JVC people solved this by using a perforated board and cemented excelsior board. The perforated board, of course, was part of their Helmholtz system. A perforated plywood layer having a high percentage of its area in holes might provide adequate load distribution.

Their cemented excelsior board apparently has its counterpart in this country in such products as National Gypsum's Tectum which might serve satisfactorily as a mechanical protection for the Soundblox. Here are the elements of a possible studio floor with acoustical advantages, but in strong need of further study and experimental verification.

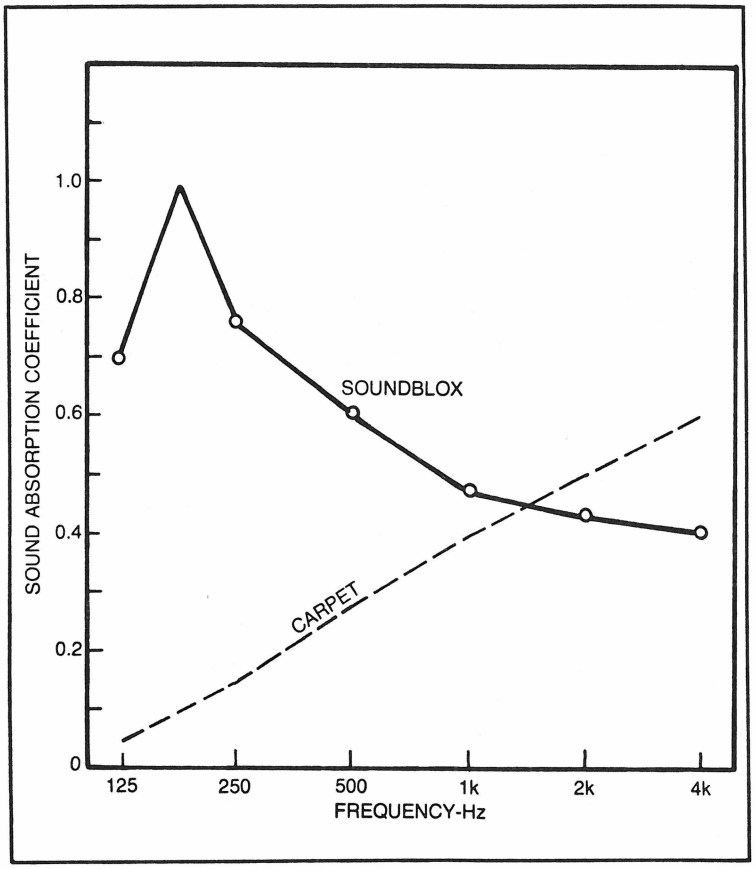


Fig. 16-10. Sound absorption characteristic of 8 inch Type R Soundblox tends to compensate for carpet absorption. This suggests the possibility of mounting Soundblox on the floor under the carpet.

THE CHEAPEST WIDEBAND ABSORBERS

For a truly budget studio there is need for an absorbing panel having respectable characteristics and of very low cost. Glass fiber panels 24 inches × 48 inches × 2 inches and 3 pounds per cubic foot density cost something like $3.00 each. The crudest and cheapest approach would be to slap a few gobs of acoustical tile cement on the back of the raw panel and stick it to the wall. By expending a modicum of imagination and effort, the panel can be covered with cloth of some sort which will not only control the irritating glass fibers but add a touch of class and color.

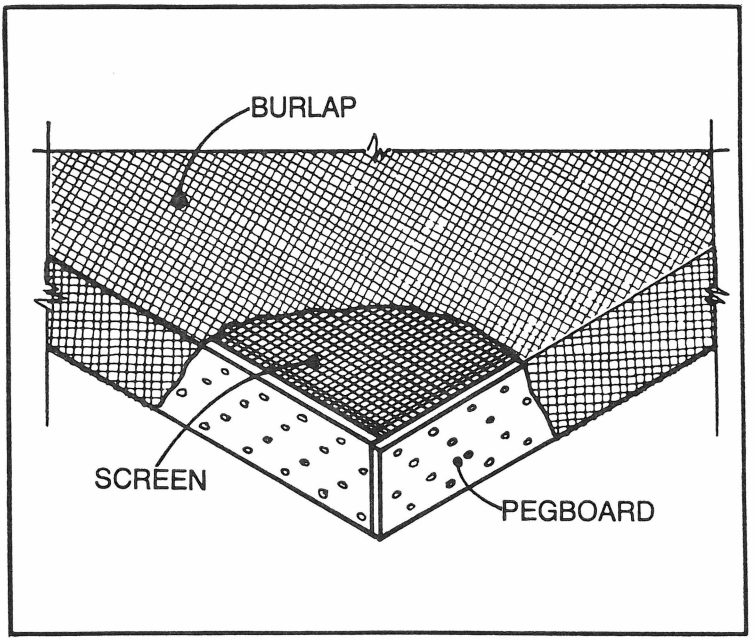


Fig. 6-11. An inexpensive homemade absorbing unit made by reinforcing the edges of a panel of 3 pounds per cubic foot density glass fiber with pegboard and stretching burlap over it, then cementing the cloth on the back of the panel. A screen may be used if impact resistance is required.

All budget approaches have their compromises. Stretching cloth over the panel tends to round off the corners and destroy the neat shape. The panels of glass fiber are fragile. If gentle handling can be guaranteed, no problem, but the first elbow blow will be memorialized permanently. All of these disadvantages can be at least minimized by building the panels along the line of that described in Fig. 16-11.

Edge absorption can be largely retained by using edge boards of pegboards as thin as available. Impact insurance is in the form of a wire screen, perforated plastic sheet (20 per cent perforation or greater), or plastic fly screen. The cloth cover should be of light weight and loosly woven. Burlap is a possibility and it is available in many colors or you can tie-dye your own! The cloth is wrapped tightly around the edge boards and cemented on the back with acoustical tile cement. Mounting the panel to the wall can be done in a rather unrelenting way with cement. The panel is so light, 4 pounds for the glass fiber

plus edge boards and cloth, it could be supported easily by a couple of rings attached to the panel by a cemented cloth tape.

The 2 inch depth of the panel carries with it poorer absorption coefficients at 125 Hz (0.18) and 250 Hz (0.76). If panels are built of two 2 inch thicknesses, good absorption could be expected down to and including 125 Hz.

Appendix A

COEFFICIENTS OF GENERAL BUILDING MATERIALS AND FURNISHINGS

Complete tables of coefficients of the various materials that normally constitute the interior finish of rooms may be found in the various books on architectural acoustics. The following shon list of materials give approximate values which will be useful in making simple calculations of the reverberation in rooms.

Materials	Coefficients					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Brick, unglazed	.03	.03	.03	.04	.05	.07
Brick, unglazed, painted	.01	.01	.02	.02	.02	.03
Carpet						
1/8" Pile Height	.05	.05	.10	.20	.30	.40
1/4" Pile Height	.05	.10	.15	.30	.50	.55
3/16" combined Pile & Foam	.05	.10	.10	.30	.40	.50
5/16" combined Pile & Foam	.05	.15	.30	.40	.50	.60
Concrete Block, painted	.10	.05	.06	.07	.09	.08
Fabrics						
Light velour, 10 oz. per sq. yd., hung straight, in contact with wall	.03	.04	.11	.17	.24	.35
Medium velour, 14 oz. per sq. yd., draped to half area	.07	.31	.49	.75	.70	.60
Heavy velour, 18 oz. per sq. yd., draped to half area	.14	.35	.55	.72	.70	.65

Floors						
Concrete or Terrazzo	.01	.01	.01	.02	.02	.02
Linoleum, asphalt, rubber or cork tile on concrete	.02	.03	.03	.03	.03	.02
Wood	.15	.11	.10	.07	.06	.07
Wood parquet in asphalt on concrete	.04	.04	.07	.06	.06	.07
Glass						
¼", sealed, large panes	.05	.03	.02	.02	.03	.02
24 oz., operable windows (in closed condition)	.10	.05	.04	.03	.03	.03
Gypsum Board, ½" nailed to 2 × 4's 16" o.c., painted	.10	.08	.05	.03	.03	.03
Marble or Glazed Tile	.01	.01	.01	.01	.02	.02
Plaster, gypsum or lime,						
rough finish on lathe	.02	.03	.04	.05	.04	.03
Same, with smooth finish	.02	.02	.03	.04	.04	.03
Hardwood Plywood paneling ¼" thick, Wood Frame	.58	.22	.07	.04	.03	.07
Water Surface, as in a swimming pool	.01	.01	.01	.01	.02	.03
Wood Roof Decking, tongue-and-groove cedar	.24	.19	.14	.08	.13	.10
Air, Sabins per 1000 cubic feet at 50% RH				.9	2.3	7.2

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Appendix B

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
None	1" 703	.06	.20	.65	.90	.95	.98
¼" Pegboard	1" 703	.08	.32	.99	.76	.34	.12
⅛" Pegboard	1" 703	.09	.35	.99	.58	.24	.10
None	1" TIW Type I	.11	.33	.70	.80	.86	.85
¼" Pegboard	1" TIW Type I	.08	.41	.99	.82	.26	.32
1" Nubby Glass Cloth Board	None	.04	.21	.73	.99	.99	.90
1" Linear Glass Cloth Board	None	.03	.17	.63	.87	.96	.96

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
None	2" 703	.18	.76	.99	.99	.99	.99
¼" Pegboard	2" 703	.26	.97	.99	.66	.34	.14
Perforated Metals	2" 703	.18	.73	.99	.99	.97	.93
1" Linear Glass Cloth	1" 703	.18	.71	.99	.99	.99	.99
1" Nubby Glass Cloth Board	1" 703	.25	.76	.99	.99	.99	.97
None	2" TIW Type I	.25	.75	.99	.99	.99	.99
¼" Pegboard	2" TIW Type I	.26	.89	.99	.58	.26	.17
Perforated Metal	2" TIW Type I	.25	.64	.99	.97	.88	.92
1" Linear Glass Cloth	1" TIW Type I	.23	.72	.99	.99	.99	.99
1" Nubby Glass Cloth	1" TIW Type I	.26	.75	.99	.99	.99	.99
1" Linear Glass Cloth	1" Air space	.04	.26	.78	.99	.99	.98

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
None	3" 703	.53	.99	.99	.99	.99	.99
¼" Pegboard	3" 703	.49	.99	.99	.69	.37	.15
1" Linear Glass Cloth	2" 703	.59	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	2" 703	.50	.99	.99	.99	.99	.97
None	3" TIW Type I	.46	.99	.99	.99	.99	.99
¼" Pegboard	3" TIW Type I	.53	.99	.97	.51	.32	.16
1" Linear Glass Cloth	2" TIW Type I	.48	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	2" TIW Type I	.51	.99	.99	.99	.97	.95
1" Linear Glass Cloth	2" Air space	.17	.40	.94	.99	.97	.99

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
None	4" 703	.99	.99	.99	.99	.98	.98
¼" Pegboard	4" 703	.80	.99	.99	.71	.38	.13
1" Linear Glass Cloth	3" 703	.88	.99	.99	.99	.93	.98
1" Nubby Glass Cloth	3" 703	.75	.99	.99	.99	.99	.97
None	4" TIW Type I	.57	.99	.99	.99	.99	.99
¼" Pegboard	4" TIW Type I	.70	.99	.94	.58	.37	.19
1" Linear Glass Cloth	3" TIW Type I	.77	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	3" TIW Type I	.71	.99	.99	.99	.99	.92
1" Linear Glass Cloth	3" Air space	.19	.53	.99	.99	.92	.99

[1]Absorption values would be unchanged for open facings such as wire mesh metal lathe, or light fabric.
[2]Perforated 1/4" holes, 1" o.c.
[3]Perforated 1/8" holes, 1" o.c.
[4]24 gauge, 3/32" holes, 13% open area.

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
None	5" 703	.95	.99	.99	.99	.99	.99
¼" Pegboard	5" 703	.98	.99	.99	.71	.40	.20
1" Linear Glass Cloth	4" 703	.87	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	4" 703	.88	.99	.99	.99	.99	.96
None	5" TIW Type I	.83	.99	.99	.99	.99	.99
¼" Pegboard	5" TIW Type I	.78	.99	.89	.63	.34	.14
1" Linear Glass Cloth	4" TIW Type I	.77	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	4" TIW Type I	.79	.99	.99	.99	.99	.98

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
None	6" 703	.99	.99	.99	.99	.99	.99
¼" Pegboard	6" 703	.95	.99	.98	.69	.36	.18
1" Linear Glass Cloth	5" 703	.99	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	5" 703	.92	.99	.99	.99	.99	.99
None	6" TIW Type I	.93	.99	.99	.99	.99	.99
¼" Pegboard	6" TIW Type I	.95	.99	.88	.64	.36	.17
1" Linear Glass Cloth	5" TIW Type I	.87	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	5" TIW Type I	.92	.99	.99	.99	.99	.93
1" Painted Linear Glass Cloth	5" Air space	.41	.73	.99	.98	.94	.97

Facing Material	Core Material	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
1" Linear Glass Cloth	6" 703	.86	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	6" 703	.85	.99	.99	.99	.99	.99
1" Linear Glass Cloth	6" TIW Type I	.95	.99	.99	.99	.99	.99
1" Nubby Glass Cloth	6" TIW Type I	.95	.99	.99	.99	.99	.94

* All material combinations installed and tested against a solid wall (i.e., #4 mounting) TIW = Thermal Insulating Wool

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Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
None[1]	1" 703	.06	.20	.65	.90	.95	.98	.70
¼" Pegboard[2]	1" 703	.08	.32	.99	.76	.34	.12	.60
⅛" Pegboard[3]	1" 703	.09	.35	.99	.58	.24	.10	.55
None	1" TIW Type I	.11	.33	.70	.80	.86	.85	.65
¼" Pegboard	1" TIW Type I	.08	.41	.99	.82	.26	.32	.60
1" Nubby Glass Cloth Board	None	.04	.21	.73	.99	.99	.90	.75
1" Textured Glass Cloth Board [5]	None	.05	.22	.67	.93	.99	.95	.70
1" Painted Linear Glass Cloth Board	None	.03	.17	.63	.87	.96	.96	.65

Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
None	2" 703	.18	.76	.99	.99	.99	.99	.95
¼" Pegboard	2" 703	.26	.97	.99	.66	.34	.14	.75
Perforated Metals[4]	2" 703	.18	.73	.99	.99	.97	.93	.95
1" Painted Linear Glass Cloth Board	1" 703	.18	.71	.99	.99	.99	.99	.90
1" Nubby Glass Cloth Board	1" 703	.25	.76	.99	.99	.99	.97	.95
None	2" TIW Type I	.25	.75	.99	.99	.99	.99	.95
¼" Pegboard	2" TIW Type I	.26	.89	.99	.58	.26	.17	.70
Perforated Metal	2" TIW Type I	.25	.64	.99	.97	.88	.92	.90
1" Linear Glass Cloth Board	1" TIW Type I	.23	.72	.99	.99	.99	.99	.90
1" Nubby Glass Cloth Board	1" TIW Type I	.26	.75	.99	.99	.99	.99	.95
1" Linear Glass Cloth Board	1" Air space	.04	.26	.78	.99	.99	.98	.75

Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
None	3" 703	.53	.99	.99	.99	.99	.99	.95
¼" Pegboard	3" 703	.49	.99	.99	.69	.37	.15	.75
1" Painted Linear Glass Cloth Board	2" 703	.59	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	2" 703	.50	.99	.99	.99	.99	.97	.95
None	3" TIW Type I	.46	.99	.99	.99	.99	.99	.95
¼" Pegboard	3" TIW Type I	.53	.99	.97	.51	.32	.16	.70
1" Painted Linear Glass Cloth Board	2" TIW Type I	.48	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	2" TIW Type I	.51	.99	.99	.99	.97	.95	.95
1" Painted Linear Glass Cloth Board	2" Air space	.17	.40	.94	.99	.97	.99	.85

Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
None	4" 703	.99	.99	.99	.99	.98	.98	.95
¼" Pegboard	4" 703	.80	.99	.99	.71	.38	.13	.75
1" Painted Linear Glass Cloth Board	3" 703	.88	.99	.99	.99	.93	.98	.95
1" Nubby Glass Cloth Board	3" 703	.75	.99	.99	.99	.99	.97	.95
None	4" TIW Type I	.57	.99	.99	.99	.99	.99	.95
¼" Pegboard	4" TIW Type I	.70	.99	.94	.58	.37	.19	.70
1" Painted Linear Glass Cloth Board	3" TIW Type I	.77	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	3" TIW Type I	.71	.99	.99	.99	.99	.92	.95
1" Painted Linear Glass Cloth Board	3" Air space	.19	.53	.99	.99	.92	.99	.85

[1]Absorption values would be unchanged for open facings such as wire mesh metal lathe, or light fabric.
[2]Perforated 1/4" holes, 1" o.c.
[3]Perforated 1/8" holes, 1" o.c.
[4]24 gauge, 3/32" holes, 13% open area.
[5]Absorption values of textured glass cloth may be interpolated to lie between linear and nubby glass cloth for all other thicknesses of wall treatment.

TIW = Thermal insulating wool

Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
None	5" 703	.95	.99	.99	.99	.99	.99	.95
¼" Pegboard	5" 703	.98	.99	.99	.71	.40	.20	.75
1" Painted Linear Glass Cloth Board	4" 703	.87	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	4" 703	.88	.99	.99	.99	.99	.96	.95
None	5" TIW Type I	.83	.99	.99	.99	.99	.99	.95
¼" Pegboard	5" TIW Type I	.78	.99	.89	.63	.34	.14	.70
1" Painted Linear Glass Cloth Board	4" TIW Type I	.77	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	4" TIW Type I	.79	.99	.99	.99	.99	.98	.95

Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
None	6" 703	.99	.99	.99	.99	.99	.99	.95
¼" Pegboard	6" 703	.95	.99	.98	.69	.36	.18	.75
1" Painted Linear Glass Cloth Board	5" 703	.99	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	5" 703	.92	.99	.99	.99	.99	.99	.95
None	6" TIW Type I	.93	.99	.99	.99	.99	.99	.95
¼" Pegboard	6" TIW Type I	.95	.99	.88	.64	.36	.17	.70
1" Painted Linear Glass Cloth Board	5" TIW Type I	.87	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	5" TIW Type I	.92	.99	.99	.99	.99	.93	.95
1" Painted Linear Glass Cloth Board	5" Air space	.41	.73	.99	.98	.94	.97	.90

16" O.C. Wood Studs	Facing	Insulation	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
2 x 2's	None	2¼" Fiberglas	.30	.69	.94	.92	.92	.98	.85
2 x 4's	None	3½" Fiberglas	.34	.80	.99	.97	.97	.92	.95
2 x 4's	1" Painted Linear Glass Cloth Board	3½" Fiberglas	.66	.99	.99	.99	.99	.97	.95
2 x 4's	1" Nubby Glass Cloth Board	3½" Fiberglas	.67	.99	.99	.99	.99	.90	.95
2 x 4's	¼" Pegboard	3½" Fiberglas	.45	.99	.87	.41	.30	.14	.70
2 x 4's	None	Paper faced* 3½" Fiberglas	.38	.96	.99	.68	.47	.35	.80
2 x 4's	1" Painted Linear Glass Cloth Board	Paper faced* 3½" Fiberglas	.66	.99	.99	.96	.99	.99	.95
2 x 4's	1" Nubby Glass Cloth Board	Paper faced* 3½" Fiberglas	.66	.99	.99	.98	.99	.95	.95
2 x 4's	¼" Pegboard	Paper faced* 3½" Fiberglas	.50	.99	.70	.41	.38	.27	.60
2 x 6's	None	6" Fiberglas	.67	.99	.99	.99	.99	.98	.95
2 x 6's	1" Painted Linear Glass Cloth Board	6" Fiberglas	.89	.99	.99	.99	.99	.99	.95

*Paper is either exposed or between insulation and facing.

Facing Material	Core Material	Absorption Coefficients 125	250	500	1000	2000	4000	NRC
1" Painted Linear Glass Cloth Board	6" 703	.86	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	6" 703	.85	.99	.99	.99	.99	.99	.95
1" Painted Linear Glass Cloth Board	6" TIW Type I	.95	.99	.99	.99	.99	.99	.95
1" Nubby Glass Cloth Board	6" TIW Type I	.95	.99	.99	.99	.99	.94	.95

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